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U.S. Department of Transportation
National Highway Traffic Safety Administration

Reliability Study of Automatic and Manual Restraint Systems. Volume 1

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16. Abstract

Evaluation of the reliability of automatic seat belt restraint systems on the 1975-1980 Volkswagen Rabbit, 1980 Chevrolet Chevette, and some 1980 Toyota Corona's is presented. The reliability of manual seat belt systems employed on these vehicles is also evaluated for comparison. Effects of system age and use, determined by acquisition and experimental testing of new and used systems, (from 4 geographic areas) with known user histories, is also reported. A comprehensive statistical model for seat belt reliability evaluation using data obtained through experimental testing and vehicle Federal Motor Vehicle Safety Standard (FMVSS) compliance testing is presented. User reports of restraint system difficulties, obtained in contacts with over 1500 users, are tabled, and recommendations for further research offered.

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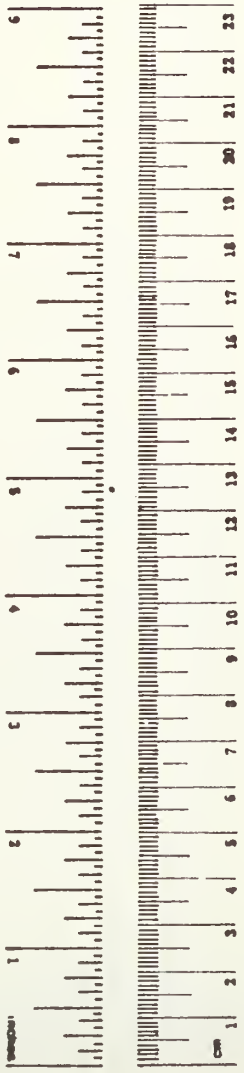
Approximate Conversions to Metric Measures

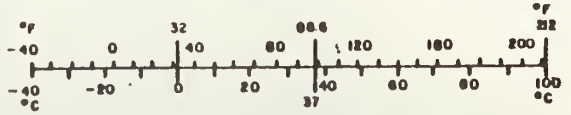
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ABSTRACT

Evaluation of the reliability of automatic seat belt restraint systems on the 1975-80 Volkswagen Rabbit, 1980 Chevrolet Chevette, and some 1980 Toyota Coronas is presented. The reliability of manual seat belt systems employed on these vehicles is also evaluated for comparison. Effects of system age and use, determined by acquisition and experimental testing of new and used systems, (from 4 geographic areas) with known user histories, is also reported. A comprehensive statistical model for seat belt reliability evaluation using data obtained through experimental testing and vehicle FMVSS compliance testing is presented. User reports of restraint system difficulties, obtained in contacts with over 1500 users, are tabled, and recommendations for further research offered.

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1.0 INTRODUCTION AND SUMMARY

This is the final report in Failure Analysis Associates' performance of services specified in NHTSA Contract No. DTNH22-80-C-07609 "Reliability Study of Automatic and Manual Restraint Systems." It summarizes all effort, findings, conclusions, and recommendations evolved during the course of this program.

1.1 BACKGROUND

The purpose of this program was to analyze the reliability of three existing automatic belt systems and consider, as was possible, the effects of various degrees of restraint readiness. The degree of restraint readiness can be generally defined as the extent to which the restraint is available for use by the vehicle occupant. Readiness is decreased by factors which reduce usage even though the system could provide restraint during a collision if used, such as twisted belts or sticky retractors.

Federal Motor Vehicle Safety Standard No. 208, in effect at the time of this contract award, required that automatic restraint systems be installed in all 1982 model year full-sized passenger cars, and for the 1984 model year, all passenger cars. The two most investigated means of automatic restraint under field evaluation by automobile manufacturers are impact activated air cushions (air bags) and automatic seat belt systems.

Three vehicle manufacturers have offered automatic belt systems as options in certain models prior to the 1982 mandatory date; the 1975-80 model year Volkswagen Rabbit, the 1980 model year Chevrolet Chevette, and a very limited edition of the 1980 model year Toyota Corona.

Each system has somewhat different design features. The Rabbit system utilizes an upper torso webbing restraint and a knee bolster pelvic restraint. The Chevette system, on the other hand, employs both torso and pelvic webbing.

The unique system is the Corona automatic torso webbing, manual pelvic webbing restraint. The uniqueness stems from an electric motor driven rack and gear drive system which moves the torso webbing attachment along a guide rail above the door. These systems are discussed in detail in Section 4.0 of this report.

1.2 OBJECTIVES

Specific objectives, which were set forth at the outset of the project, are listed below. They follow logically from the global program goal of analyzing the reliability of the three systems previously described. The degree of completion of these objectives was obviously affected by cooperation of manufacturers, vehicle owners, and the constraints associated with vehicle owner contact.

1. Evaluate reliability models for application to automatic and manual seat belt systems.

2. Review sampling strategies for those which reduce testing a specific restraint system to as few sample systems as possible.
3. Quantify reliability and confidence levels, if possible, of the three available automatic seat belt systems.
4. Compare reliability levels of existing manual and automatic seat belt systems.
5. Evaluate the degree of belt system degradation with use.
6. Determine achievable reliability, and estimate, if possible, the cost impact based of recommended improvements in restraint system components.
7. To the extent possible develop guidelines for establishing reliability requirements for automatic belt systems.
8. Estimate the degree of restraint readiness of examined automatic and manual seat belt systems.

1.3 CONCLUSIONS AND SUMMARY

1.3.1 CONCLUSIONS

The conclusions drawn from the project are summarized below.

1. Table 1.1 shows a summary of the calculated belt system reliabilities, for both manual and automatic systems, in the new and five (5) year old condition. Details of testing and results are discussed in Sections 4.2 and 4.3 and the reliability analysis is presented in Section 5.

The estimated seat belt system reliabilities depended primarily on two factors: (1) load strengths of new and used components compared to load imparted during vehicle frontal impact testing at approximately 30 mph and, (2) retractor acceleration/engagement testing of new and used components and subsequent webbing extension when subjected to a .7g acceleration. This acceleration level was chosen since FMVSS No. 208 test data do not present retractor acceleration information and FMVSS No. 209 requires retractor engagement with a maximum one inch webbing extension when subjected to 0.7g's. In general the seat belt system reliabilities are dominated by webbing extension upon retractor acceleration.

2. Inclusion of the manual lap belt with the automatic shoulder belt for the Toyota Corona increases the calculated seat belt system reliability by two orders of magnitude.

   The Toyota Corona electric motor driven automatic shoulder belt system is complimented by a manual lap belt system. Due to the component strengths and retractor extensions established for Toyota manual components and an assumed redundancy in restraint of two independent retractor/webbing/buckle systems greatly enhanced the calculated system reliability (see Table 1.1). These estimates assume that the Toyota electric motor drive system does not affect belt system reliability and that

failure of each independent system (lap and shoulder) is necessary to not restrain an occupant.

3. Retractors and buckles show trends in degradation of strength from usage while webbing exhibits trends in degradation of strength from aging independent of usage.

   By examining load strength data for various belt systems where used driver/passenger pairs were obtained, it was possible to estimate differences between usage and age independently assuming the driver's side belt system is used more frequently. However, sparsity of data and lack of manufacturer supplied design and test information produced erratic variances. This precluded quantifying the expected reduction due to age and wear of seat belt system reliability. In addition, lot quality, possible material changes, or design changes may be sufficient to affect or reverse the trends in load strength reduction as described in Section 5.4.

4. Sparsity of data and assumptions necessary for reliability estimates inhibit a realistic quantitative comparison of seat belt system reliability between manufacturers.

   The distribution of seat belts accessible for testing by location and model year were not the same for all manufacturers. Therefore, comparisons of reliabilities estimated from this population may be invalid. Also since

pre-1979 Toyota Corona retractor/webbing extension data were not obtained, an average of VW Rabbit and Chevrolet Chevette retractor/webbing extension characteristics was used to estimate the reliability of Toyota Corona manual belt systems.

These manual belt systems incorporate a remote switch mounted in the vehicle body to sense changes in vehicle acceleration. The retractor locking mechanism is activated by a solenoid contained within the retractor. These systems, therefore, did not undergo laboratory acceleration/engagement testing designed to analyze latch effectiveness by accelerating the retractor itself.

5. The hardware identification program reached a 27% section of 5805 original owners of selected vehicle models in four geographical areas. The information obtained from the hardware identification program can not, with any reasonable degree of confidence, be utilized for reliability analyses or statistical evaluation of restraint readiness since the program was not intended as a population survey. Nevertheless the results of that program can be stated as follows:

   - 76 to 85 percent of those owners reached reportedly used their seat belt systems often.

- Among those who reportedly used their belts often approximately five (5) percent reported apparent failures of seat belt system components.
- Among those contacted who used their belt systems often, approximately thirty-four (34) percent reported problems relating to reliability and/or restraint readiness.
- A comparison of manufacturers concerning reliability or restraint readiness problems identified during the hardware identification was not performed with the data obtained from this population due to the nature of the sample.
- In the case of VW Rabbits the data show that automatic belt systems with components equivalent to, but fewer in number (i.e., no lap belt) than manual belt systems generate fewer reported problems and failures per user.

1.3.2 SUMMARY OF METHOD

Figure 1.1 shows the method of approach used to quantify the reliability of manual and automatic seat belt systems. The key to program execution was the location and procurement of used seat belt systems with known service histories. Since the reliability of seat belt systems as a function of age and usage was desired with an emphasis on automatic systems, it was necessary to procure used systems to make this evaluation.

Identification and procurement of such systems was accomplished by:

1. Computer analysis of vehicle registration maintained by R.L. Polk to find names and addresses of owners who purchased new and still owned their vehicles.
2. Telephone contact by FAA engineering personnel to find seat belt systems that were being used and might possibly have problems (this effort was not intended to be a population survey, and was not conducted in that manner).
3. Secondary contact by FAA personnel for owner cooperation in used system replacement.
4. Owner participation in visiting local dealerships for belt system replacement.

Step 4 of this process was primarily limited to owners whose seat belt systems were malfunctioning since only two owners of some 200 contacted, whose seat belts were without apparent problems, would voluntarily cooperate. Out of 434 users who reported some problem with their vehicle's restraint system, 41 systems taken from 26 vehicles were acquired and tested. Budgetary constraints were prohibitive for remuneration of owners as an incentive to participate which would be required to obtain a scientifically selected survey sample. Thus systems tested totalled 43. Therefore, the sample was reduced to basically systems with obvious degradation or failures.

In addition, since the hardware identification program (telephone contact of owners) was not a designed survey the

information gained which relates to restraint readiness should not be incorporated directly into reliability or restraint readiness statistical analyses. Therefore, the restraint readiness data are presented in summary percentage form in Section 5.6.

FAA requested assistance from the three manufacturers, Volkswagen, General Motors, and Toyota, however none was given. Therefore, information necessary for reliability analysis such as system design loads, system design changes, materials changes, service loads, and frictional factors, were approximated or assumed from best engineering judgements by FAA. Details of those assumptions are addressed where applicable throughout the report.

To develop the best standards for automatic restraint systems an optimum seat belt system performance criteria would be extremely helpful, especially one that considered and cost impact consideratons. Without manufacturer input, however, approximations of cost impact of system design changes would not have sufficient accuracy. In addition, development of true optimum performance criteria might require proprietary information in addition to reliable statistical information. A discussion of the considerations and procedures for determining optimum performance criteria is included in Section 2.2.

Component strength testing was accomplished for new and degraded components, and is presented in Section 4.2. This strength testing, in conjunction with retractor acceleration

engagement testing, and the webbing loads recorded in certain FMVSS No. 208 tests, are used in the reliability analysis of manual and automatic belt systems. Based upon the previously discussed technical constraints associated with these analyses. FAA considers these reliability analyses to be the best estimates obtainable from the data.

Recommendations are presented in section 6.0 to address the requirements for a more accurate reliability analysis. In addition, since the reliability analysis conducted herein identifies the retractor mechanism as the component having the greatest impact on seat belt system reliability, an engineering design analysis of retractors is recommended prior to any changes in current regulatory standards.

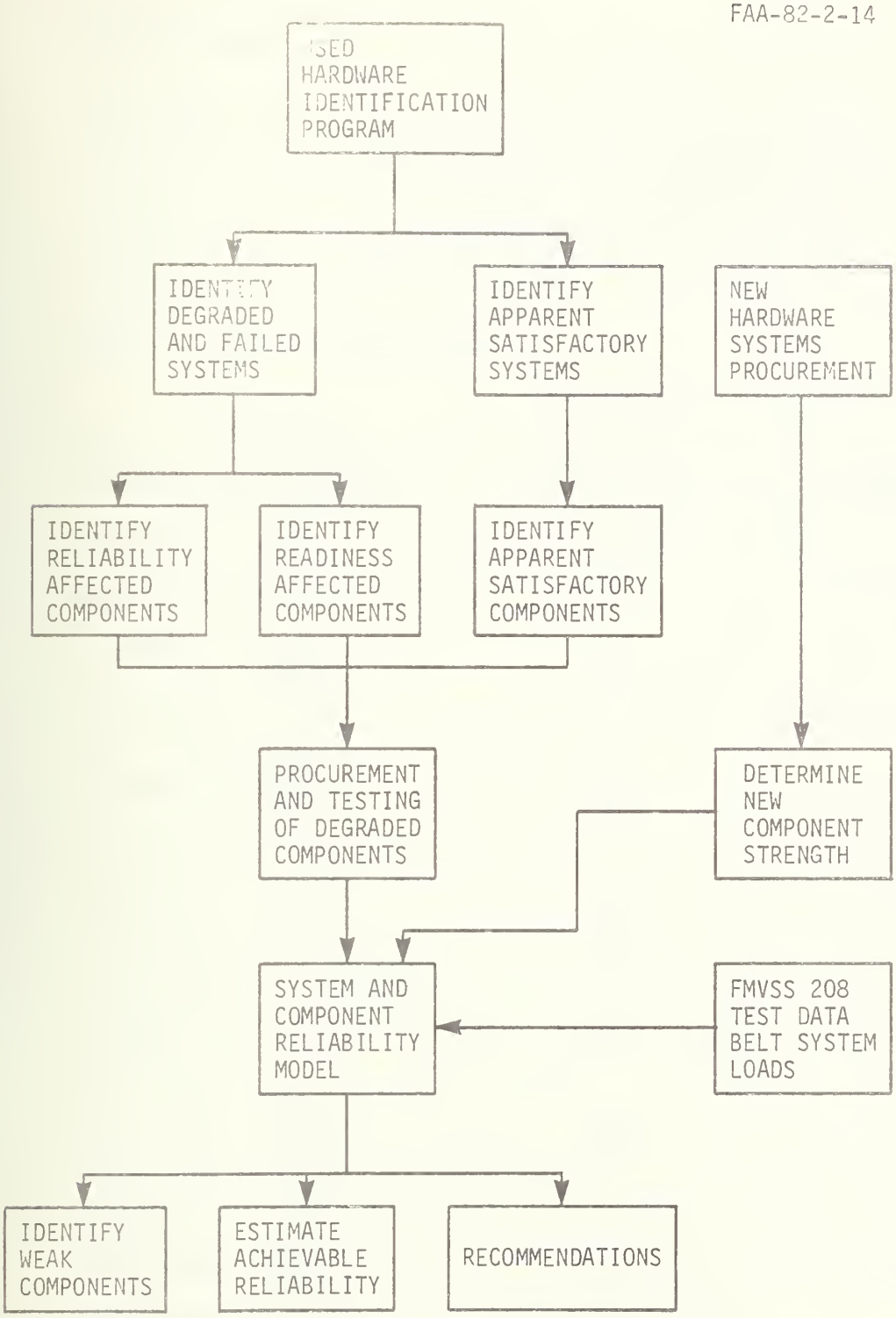


Figure 1.1 - Flow Chart Showing the Interaction of Data Collection and Analysis Method for Determining System and Component Reliability.

TABLE 1.1

Estimated Seat Belt System Reliabilities
for 29.4 mph Vehicle Frontal Impact
and 0.7g Retractor Acceleration
(Based on results from 43 systems tested)

Seat Belt System	Vehicle/Belt System Age (Years)	Estimated Reliability*
Toyota Corona Manual System Pre-1979	New	.995
	5	.984
Toyota Corona Automatic Shoulder Belt	New	.995
	5	.995
Toyota Corona Automatic Shoulder Belt w/Manual Lap Belt	New	.9999+
	5	.9999+
Volkswagen Rabbit Manual System	New	.99
	5	.99
Volkswagen Rabbit Automatic System	New	.99
	5	.99
Chevrolet Chevette Manual System	New	.997
	5	.997
Chevrolet Chevette Automatic System	New	.997
	5	.997

* Best estimate based on available data. See Section 5 for detailed discussion of reliability analysis.

2.0 PROGRAM SUMMARY

The program was divided into four tasks that combined review of existing literature, acquisition of actual used systems, experimental evaluation of new and used systems, and analysis to produce the final reliability estimate.

2.1 TASK 1 - WORK PLAN AND METHODOLOGY

The initial thirty (30) day program effort was dedicated to refinement of the program method and developing the work plan. Discussions between FAA and the NHTSA technical manager resulted in modifications to the scope of work as defined in the original proposal (FAA-P-80-8-1).

The agreed upon work plan called for review of existing literature, combined experimental and analytical effort.

The reliability model selected combined data from restraint systems with (1) Obviously failed components identified during the hardware identification program; (2) experimentally determined reduction in strength due to age and use of various components; (3) component loads upon vehicle frontal collisions at approximately 30 mph, taken from FMVSS No. 208 test data; (4) experimentally determined retractor acceleration/engagement data and; (5) manual and automatic belt system definitions. The required data is gathered in tasks 2 and 3, and the model is then exercised as task 4.

In addition, restraint readiness is presented in percent summary form with the results of the hardware identification program and subject belt system inspection.

2.2 TASK 2 - LITERATURE REVIEW AND HARDWARE IDENTIFICATION PROGRAM

This task involved collecting existing analysis and data required to execute the reliability analysis. In addition, review of existing performance criteria for restraint systems were also examined, with an eye toward the goal of establishing optimum cost/benefit performance criteria.

2.2.1 FMVSS No. 208 Test Data

The approach to reliability modeling as chosen by FAA required the review of Federal Motor Vehicle Safety Standard (FMVSS) No. 208 test data for the vehicles systems under evaluation. The reliability analysis considers not only the current obvious state of the hardware (e.g., broken retractor, worn belt, etc.) but also whether the component, although currently competent, will fail when subjected to loading during a collision. Therefore, the magnitudes of belt system loading during collisions of different severities is important. Review of FMVSS No. 208 compliance tests showed load vs. time graphs for components such as lap and torso belts which could be used to ascertain the loading information desired. However, since FMVSS No. 208 requires frontal impact speed of approximately 30 miles per hour (mph) no crash data other than those shown in Table 2.1 were found for the vehicles in question. Requests were made to the vehicle manufacturers for any additional crash test data which could be utilized in the analysis (see Appendix A), but none was obtained. Copies of

the FMVSS No. 208 test data which were used in the reliability analysis are shown in Appendix B.

In addition to the FMVSS No. 208 data obtained for Chevrolet Chevette, Volkswagen Rabbit, and Toyota Corona, FAA received higher speed crash data for the Chevrolet Citation. The speeds recorded were 30, 40, and 48 mph. However, due to the apparent scatter in the test data, no reasonable load vs. speed of impact relationship could be determined or applied to the test data for the Chevette, Rabbit, or Corona. Table 2.2 shows a comparison of the data reviewed.

2.2.2 Automatic Seat Belt System Optimum Performance Standards

A review of performance standards of new automatic belt systems was identified in the scope of work and discussed during Task 1 of the program. The current performance requirements for automatic belt systems are met by compliance with FMVSS No. 208, as is the case for all type 2 belt systems. FAA requested from restraint manufacturers any nonproprietary information relating to design loads or period of performance (See again Appendix A).

To develop the "optimum" cost/benefit performance criteria for restraint systems the design system load levels must be defined. In addition, since most mechanical components and systems are designed for a finite expected life, this criterion must be known. Further cost/benefit and risk analyses would then be necessary to establish a true optimum.

The steps and considerations believed necessary for a cost/benefit analysis to determine optimum seat belt performance requirements are as follows.

(1) Determine, for the population, how many fatal (injury) accidents involved occupants who properly wore their seat belts but who died (were injured) due to seat belt failure

(2) Determine, for the population, how many nonfatal (noninjury) accidents of comparable circumstances in which occupants who wore their seat belts were successfully protected.

(3) Ratio (1) to (2) to determine contribution of seat belt unreliability to death and injury and consequent accident costs over and above those had the seat belts worked.

(4) Assess cost of seat belt redesign and type of requirements including design, quality control, inspection, maintenance, etc., necessary to reduce injuries and deaths and compute cost of requirement upgrade and the total that could be saved per death or injury forestalled. Include expected dollar savings - hospital costs, litigation costs, vehicle repair costs.

(5) Apply a corresponding exercise to other motor vehicle safety factors including highway environment, highway traffic, vehicle design, vehicle inspection, and vehicle maintenance including training and licensing of auto mechanics and repair facilities to compute cost of action per death or injury forestalled and the number that could

be saved. Include expected dollar savings - hospital, litigation, investigation, property damage, vehicle repair, etc.

(6) Consider the lead time investment costs and consequences, which include management redirection, reassignment of engineering talent from other lifesaving tasks, factory retooling, training, etc., with increases in price of vehicles or taxes and interest costs and bankruptcy risks. Compute total benefit minus total social cost for the actions considered.

(7) Rank savings (benefit) in lives and dollars achieved per dollar spent for action on each factor. Accumulate total savings (benefits) possible and accumulate total cost.

(8) The seat belt requirement should be adjusted to produce and maximize a positive difference of benefit beyond social cost.

2.3 TASK 3 - EXPERIMENTAL STUDY OF SEAT BELT DEGRADATION AND COMPONENT TESTING

This task involved the acquisition of used and new retraint system components for testing. Used components were collected from several geographic locations.

2.3.1 Acquisition of Used Seat Belt Systems

Acquiring seat belt systems with known user histories in multiple geographic areas involved location of the owners,

making contact, and arranging for replacement of the used system.

2.3.1.1 Geographical Locations

By acquiring used components from several geographic areas degradation of manual belt systems as a function age also include consideration of environmental catalysts and give the results more national accuracy. Four geographical locations were chosen to encompass a variety of climatic conditions: Los Angeles, California, for salt corrosion and moisture; Phoenix, Arizona, for dust, ultraviolet exposure, and heat; Houston, Texas, for humidity and microorganisms; and Denver, Colorado, for cold, salt corrosion, and ultraviolet exposure.

The first three major metropolitan areas were chosen due to proximity to FAA offices. Denver, Colorado was chosen as a cold climate area reasonably close to the other three to minimize logistic problems associated with program management and execution. Additionally, major metropolitan areas were chosen to maximize the sample population.

2.3.1.2 Used Component Identification Program

A key aspect of the project is the used hardware identification program. This effort serves two important purposes. First and foremost, the program locates and identifies seat belt hardware with known service histories which can undergo component testing

to define functional degradation with service life. Second, any additional information supplied by owners may be used in the analysis of system restraint readiness.

The hardware identification program required the names, addresses, and telephone numbers of registered vehicle owners were required for the vehicle models selected. These models included the 1974-79 Toyota Coronas; 1976 Chevrolet Chevettes; and 1975-76, and 1979 Volkswagen Rabbits. In addition, to assure complete information on the history of possible maintenance and replacements affecting seat belts, only vehicles purchased new by their present owners could be used. FAA contacted the automotive special services branch of R.L. Polk and Company, a national marketing and distribution company, to obtain the basic registrant lists for the vehicles in question.

Some 1300 owners' names within each of the four geographical locations were thus obtained totaling 5805 registrants.

Due to a security agreement between R.L. Polk and Company and the State of Arizona, special permission was necessary for the release of vehicle registration information to FAA. Contact was made with the Assistant Director, Motor Vehicle Division, State of Arizona Department of Transportation and permission was subsequently granted (Appendix C).

2.3.1.3 Automobile Dealership Contact for Used Restraint Replacement

Local Toyota, Chevrolet, and Volkswagen dealerships and regional service managers in the four geographical areas were contacted and presented with an explanation of the hardware replacement program. The plan called for FAA to first determine which used systems identified in the owner contact portion of the project were of interest for component strength testing. Following this, FAA would determine the necessary replacement parts and order said parts. Upon subsequent dealer receipt of the replacement systems, FAA would arrange for vehicle owners to visit the dealership and receive the replacement belts. All costs associated with the replacements, parts and labor, were paid directly to the dealership by FAA.

To aid in program management and the logistics involved in such a replacement program, FAA requested from the dealerships letters of intent to cooperate as well as parts and labor cost estimates for both manual and passive seat belt sets (VW and Chevrolet only). These letters and estimates are shown in Appendix D.

2.3.2 Automobile Manufacturer Contact for Seat Belt Engineering Data

During Task 1, FAA located and contacted representatives of Volkswagen, Toyota, and General Motors, as indicated by previous reference to Appendix A. The scope of the project

was explained in detail and assistance was requested in obtaining information relating to design load parameters and any reliability data which might be available. Specifically, FAA requested information concerning:

-- Belt Loads

-- Attachment Hardware Loads

-- Buckle Loads

-- Time Dependence of Load Application

-- Retractor Lock Engagement Parameters

-- Varying Severities of Crash Testing

Unfortunately, no technical information was supplied. Mr. Richard Chitty, Technical Analysis Manager, Toyota Motor Sales, was the only representative who provided written response. He did, however, assist FAA in explaining the scope of the project to Toyota Regional Service Representatives and suggested their cooperation be given.

Representatives of General Motors Safety Research and Development Laboratory refused to cooperate or provide any assistance in the explanation of the project scope to local General Motors dealerships. Volkswagen likewise supplied no technical information, however, the dealerships were very interested in the program and little difficulty in making arrangements was experienced.

New restraint system components were secured from the various dealerships for FAA's independent testing.

2.3.3 Component Testing

Testing methods for the various components are described in detail in Section 4. Webbing and retractors in new and used condition were subject to mechanical loads and the failure frequency were observed.

2.4 TASK 4 - RELIABILITY ANALYSIS

The reliability analysis combined the data obtained in the preceeding three tasks to develop the estimates presented in Section 1. The analysis itself is presented in detail in Section 5.

VEHICLE	TEST	SPEED	REPORT NUMBER	DATE	BELT DESCRIPTION	PEAK LOAD
1978 Chevrolet Chevette	Frontal Impact	29.4 mph	671-1489-74	May 1979	Driver Torso	1597
					Passenger Torso	1534
1980 Chevrolet Chevette	Frontal Impact	35.2 mph	3102-80-120	July 1980	Driver Lap	1853
					Driver Torso	2206
					Passenger Lap	1386
					Passenger Torso	2170
1976 Volkswagen Rabbit	Frontal Impact	29.4 mph	3975-76-37	Aug. 1976	Driver Lap	1140
					Driver Torso	1280
					Passenger Lap	1678
					Passenger Torso	1025
1979 Volkswagen Rabbit	Frontal Impact	34.8 pmh	6525-V-5	July 1979	Driver Torso	1837
					Passenger Torso	1837
1980 Toyota Corona	Frontal Impact	29.4 mph	3107-80-156	Aug. 1980	Driver Torso	1884
					Passenger Torso	2141
1978 Toyota Cressida	Frontal Impact	29.6 mph	3005-78-114	Aug. 1978	Driver Lap	1212
					Driver Torso	619
					Passenger Lap	1150
					Passenger Torso	1329

Table 2.1 - Comparison of Peak Webbing Loads
During FMVSS No. 208 Testing

VEHICLE	TEST	SPEED	REPORT NUMBER	DATE	BELT DESCRIPTION	PEAK LOAD
1980 Chevrolet Citation	Frontal Impact	35.0 mph	6525-V-3	June 1979	Driver Torso	1520
					Passenger Torso	1540
1980 Chevrolet Citation	Frontal Impact	39.9 mph	6525-V-1	June 1979	Driver Torso	1580
					Passenger Torso	2100
1980 Chevrolet Citation	Frontal Impact	48.0 mph	6525-V-2	June 1979	Driver Torso	1750
					Passenger Torso	1580

Table 2.2- Comparison of Peak Webbing Loads for Increasing Speed of Impact During FMVSS No. 208 Testing.

3.0 TASK 2 - LITERATURE REVIEW AND HARDWARE IDENTIFICATION PROGRAM

The majority of the effort in Task 2 involved conducting the user hardware identification program. However, included within Task 2 was the review of statistical analysis methods and sampling techniques concerning application to seat belt system reliability analysis. In addition, FAA, having received no information from the manufacturers, independently researched reliability information associated with the unique Toyota electric automatic belt system. Review of additionally requested FMVSS No. 208 Test Data was also performed during Task 2.

3.1 STATISTICAL ANALYSIS AND SAMPLING METHOD REVIEW

Assessment of seat belt systems can be viewed as a combined engineering and statistical analysis to compute reliability. Important to the effort are the statistical methods used for modeling of the seat belt system as a reliability network, parameterization of the modeling and statistical estimation, and the sampling methods for acquisition of data. A review of statistical methods for failure analysis of seat belt systems is provided within this report.

The objectives of the review are twofold. The first is to describe those methods used in this report that are not already well explained in introductory texts and handbooks on statistics which are available both in many book stores and from the Federal Government (e.g. Crow, Davis, and Maxfield (1)). The second is to provide a description of alternative methods offering a gradation of modeling detail and use of data. That is, if either less information or more information were available concerning the behavior of seat belts or vehicle

system, then we would wish to know what approaches to the modeling and statistical analysis might become appropriate. Thus, the aim of the review is indicative rather than exhaustive in providing for some flexibility on analysis approach.

In this report, the seat belt is treated as an isolated system with the vehicle represented by the mountings, the applied loads upon frontal impact, and the failing retractor webbing extension being 5 inches. For reliability assessment, reliability of the seat belt system is a function of the probabilistic behavior of its component parts and interfaces with its surroundings. Alternative mathematical descriptions for assembly of seat belt reliability are reviewed in Appendix E on the System as a Probabilistic Network Structure.

Calculation of displacement and load-strength reliability of seat belt subsystems require first a selection of modeling to characterize behavior as a function of influencing factors such as age and usage. Probably most important to subsequent analysis are the methods for using the data to estimate values for the unknown quantities (called parameters) in the modeling. These estimates will be for both the engineering or expected average values of the terms (i.e.; deterministic content of model) and random, that is, chance variations in the value of quantities (i.e.; probabilistic content of model). To assess the range of available methods, a well connected review is provided with Appendix F. Descriptions of some of the methodology used for the load strength analysis in this report do appear in the Appendix. However, the broad range of methodologies described does not permit much detail such as techniques for the

weighting of data, etc. Such details are instead described as they are needed in the course of analysis presented.

The statistical analyses to assess possible trends in the various sets of data employ what are essentially handbook techniques. However, budgetary considerations forced a reduction in the number of of component laboratory strength tests that could be run and it was anticipated that not enough data would be generated for analysis. As a consequence, the laboratory test plan was rearranged to allow seat belt components to be tested together so that nonfailure loads on the seat belt components could be produced and used as data in addition to the failure loads. Such data in which the failure load is hidden but known to be above the nonfailing load that was observed to be applied are called Type 1 censored data. In other words all failure data for any surviving components after the preset loading was reached is unknown, since the components were tested no further. Methods are available in the open literature for handling this type of censoring except for two factors which occur in this program. First, each failed component in a group is often loaded to a different level (i.e.; multiple censor levels) and second the number of components analyzed in group together is often small (i.e.; sample sizes are small). Consequently, the special techniques and computer program developed at Failure Analysis Associates for treatment of this problem were essential if the analysis was to be conducted. A complete development of the equations and algorithm for analysis is contained in Appendix G (2).

3.2 LITERATURE RELATING TO TOYOTA AUTOMATIC BELT SYSTEM ELECTRIC MOTOR RELIABILITY

An implicit requirement for estimating the reliability of any system is the accurate identification of the reliability of each system component. Peculiar to the automatic belt Toyota system is an electric motor driven rack and gear system that moves the shoulder end of the torso belt into position as shown in Figure 3.1. With direct manufacturer failure data being unavailable, a search was performed for an alternate source of information on the failure rate of similar small electric motors.

The Government-Industry Data Exchange Program (GIDEP) has established a Reliability-Maintainability Data Bank (RMDB) based on failure information supplied by various government and industry participants. An RMDB search yielded two independent references from which suitable electric motor reliability information has been extracted. An electric motor reliability prediction model (Appendix I) has been developed by Shaker Research Corporation for fractional horsepower motors with grease packed ball bearings. Motor failure rates vary from 12-102 failures/million hours,for operation in a 40-80° environment, respectively. (The simplified reliability model computes failure rates as a function solely of ambient temperature.)

If an average usage of 3 times a day is assumed for automatic seat belts on the driver side and once a day for the passenger side, then usage will total to 1460 times a year in such a vehicle. Based on information from Toyota Company representatives, the electric motor for a Toyota Corona automatic belt may be assumed to run 14 seconds

on each entry and 14 second on each exit from the vehicle. These assumptions will result in an exposure rate of 11-1/3 hours of electric motor operation per vehicle year. If this result is multiplied by the 12 to 102 failures per million hours indicated above and factored to a five year period for 1000 Toyota Corona vehicles, then the failure rate becomes

$$\frac{12 \text{ to } 102 \text{ failures}}{1{,}000{,}000 \text{ hours}} \times 11\text{-}1/3 \ \frac{\text{hours}}{\text{veh year}}$$

$$\times 1000 \text{ veh} \times 5 \text{ years} = 1 \text{ to } 6 \ \begin{matrix}\text{failures among} \\ \text{1000 vehicles} \\ \text{in 5 years}\end{matrix}$$

However, the data from Shaker Research Corporation is for continuous operation and does not include start-stops which are expected to have a heavy impact on electric motor deterioration. Thus, the results here should be considered an upper bound on electric motor reliability for seat belt use given that the Toyota Corona motors are of comparable design.

3.3 USED HARDWARE IDENTIFICATION PROGRAM

A fundamental requirement in the reliability analysis of automotive seat belt systems is the knowledge of system service histories. The scope of the program is to predict the reliability of automatic belt systems, which by definition will be used every time the vehicle is driven; therefore, it was recognized that only manual systems, which by admission of the owners are used frequently, should be used for a comparable reliability analysis. Further, it was necessary to identify obvious owner recognized belt system component failures to allow subsequent engineering inspection and testing. Owner

recognition of obvious failures was employed since the engineering manpower required to personally inspect thousands of vehicles was prohibitive. Since the reliability analysis as designed by FAA considered individual component reliabilities, any non-failed components within a system recognized to have some apparent degradation of a particular component provide additional test specimens and reliability information.

During Task 2, FAA obtained the results of the R.L. Polk and Company sort of vehicle registration information for the four geographical locations. A summary of the totals by manufacturer, model, year, and geographical location are shown in Table 3.1.

A telephone number search was subsequently conducted of these 5805 registrants, limiting the inquiry to those telephone numbers listed in public directories. This limitation reduced the total number of possible respondants to 2361. Upon receipt of the telephone numbers, FAA engineers and engineering technicians systematically contacted the original owner registrants.

The format for contact is shown in Appendix J. The discussion was not a probative survey, rather, an explanation of the research FAA was conducting and a request for any information which might prove of assistance in the reliability analysis.

Engineering personnel were employed for this effort to technically interpret any response offered. Again the prime emphasis of the program was to identify seat belt hardware which displayed obvious failures and readiness affecting problems. Since the service history

of each system is a necessary requirement, it was imperative that the owner usage of the belt systems be established. However, this information is used only to determine legitimate hardware data and does not constitute a seat belt usage survey.

Based upon information rendered by the registrants, FAA engineering personnel completed the telecon response form also shown in Appendix J. Included within the Appendix are copies of two subject forms.

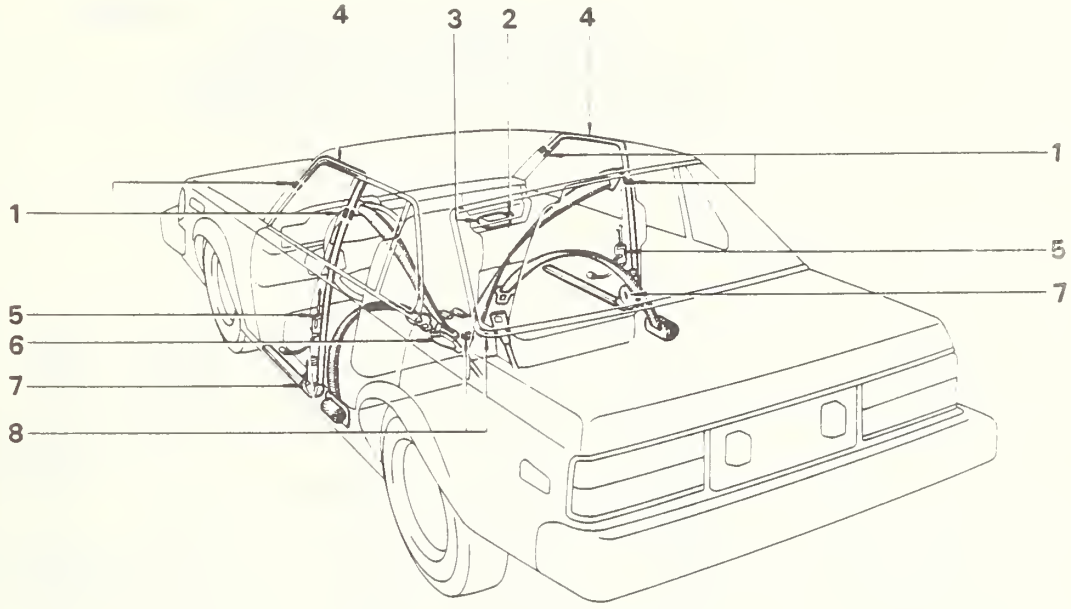
The information was then desseminated into areas which affect system reliability (its ability to perform the desired function) and restraint readiness (system could perform restraint, however some problem precluded its usage).

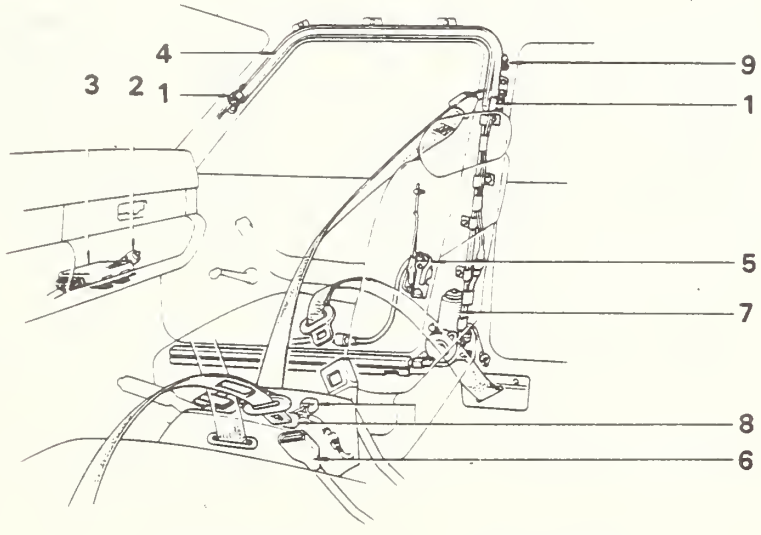
A summary of results concerning the 2361 registrants whose telephone numbers appear in public directories is shown in Tables 3.2-3.6. The response classifications are self-explanatory and those entries which fall under "no contact or response" include telephone disconnections, parties whose telephone numbers became unlisted, and persons who could not be contacted after three attempts (morning and evening) by FAA engineering personnel.

The differentiation of reliability affecting failures, readiness affecting problems, belt systems functioning properly, and systems which are not used by the owners is tabulated by geographical location in Tables 3.7-3.10

A detailed breadkdown of the reported incidences by vehicle type and model year is shown in Appendix K.

A percentage summary and discussion of readiness restraint estimates is presented in Section 5.6.





1. Limit Switch
2. Circuit Breaker
3. Computer
4. Guide Rail
5. Door Lock Switch
6. Buckle Switch
7. Motor
8. Spool Release Switch
9. Emergency Lock

Figure 3.1 - Toyota Corona Automatic Shoulder Belt System.

TABLE 3.1

Summary of Vehicle Registration Identifications
(Original Purchase Owners)
Supplied by R.L. Polk and Company

AUTOMOBILE	MODEL YEAR	PHOENIX	LOS ANGELES	HOUSTON	DENVER	TOTAL
Toyota Corona	1974	31	180	113	81	405
Toyota Corona	1975	27	76	74	49	226
Toyota Corona	1976	59	181	176	91	507
Toyota Corona	1977	85	289	216	88	678
Toyota Corona	1978	98	400	233	52	783
Toyota Corona	1979	97	372	235	25	729
Chevrolet Chevette	1976	86	213	322	165	786
Volkswagen Rabbit	1975	18	131	94	65	308
Volkswagen Rabbit	1976	72	274	135	246	727
Volkswagen Rabbit	1979	133	297	199	27	656
		706	2413	1797	889	5805

TABLE 3.2

Hardware Identification Program Summary

RESPONSE CLASSIFICATION (NO. OF VEHICLES)	PHOENIX	HOUSTON	LOS ANGELES	DENVER	TOTALS
Reliability affected, only	7	12	10	12	41
Readiness affected, only	64	93	103	105	365
Reliability & Readiness affected	9	4	8	7	28
No problems; system in use	87	372	231	168	858
Systems never used	32	151	66	52	301
Vehicle has been sold	37	153	41	71	302
No contact or response	96	90	193	87	466
TOTALS:	332	880	654	502	2361

TABLE 3.3

Summary of Results - Hardware Identification Program
Chevrolet Chevette

CHEVETTE

RESPONSE CLASSIFICATION (# OF VEHICLES)	PHOENIX	HOUSTON	LOS ANGELES	DENVER	TOTALS
RELIABILITY AFFECTED, ONLY	2	4	0	0	6
READINESS AFFECTED, ONLY	7	13	6	27	53
RELIABILITY & READINESS AFFECTED	4	0	1	3	8
NO PROBLEMS; SYSTEM IN USE	10	50	16	25	101
SYSTEMS NEVER USED	5	21	7	13	46
VEHICLE HAS BEEN SOLD	3	32	6	17	58
NO CONTACT OR RESPONSE	10	17	8	10	45
TOTALS	41	137	44	95	317

TABLE 3.4

Summary of Results - Hardware Identification Program
Toyota Corona

CORONA

RESPONSE CLASSIFICATION (# OF VEHICLES)	PHOENIX	HOUSTON	LOS ANGELES	DENVER	TOTALS
RELIABILITY AFFECTED, ONLY	2	7	5	8	22
READINESS AFFECTED, ONLY	30	50	64	44	188
RELIABILITY & READINESS AFFECTED	2	2	6	3	13
NO PROBLEMS; SYSTEMS IN USE	51	225	144	92	512
SYSTEMS NEVER USED	19	101	50	28	198
VEHICLE HAS BEEN SOLD	17	78	18	28	141
NO CONTACT OR RESPONSE	49	47	117	27	240
TOTALS	170	510	404	230	1314

TABLE 3.5

Summary of Results - Hardware Identification Program
Volkswagen Rabbits with Manual Seat Belt Systems

RABBIT (MANUAL)

RESPONSE CLASSIFICATION (# OF VEHICLES)	PHOENIX	HOUSTON	LOS ANGELES	DENVER	TOTALS
RELIABILITY AFFECTED, ONLY	3	1	2	4	10
READINESS AFFECTED, ONLY	25	13	23	25	86
RELIABILITY & READINESS AFFECTED	3	1	1	1	6
NO PROBLEMS; SYSTEMS IN USE	18	53	32	27	130
SYSTEMS NEVER USED	8	26	4	9	47
VEHICLE HAS BEEN SOLD	(17)*	(43)*	(17)*	(26)*	(103)*
NO CONTACT OR RESPONSE	(37)*	(26)*	(68)*	(50)*	(181)*
TOTALS	*	*	*	*	*

*Totals in parenthesis reflect combined totals for manual and automatic VW Rabbit Systems.

Failure
Analysis
Associates
FAA-82-2-14

TABLE 3.6

Summary of Results - Hardware Identification Program
Volkswagen Rabbits with Automatic Seat Belt Systems

RABBIT (AUTOMATIC)

RESPONSE CLASSIFICATION (# OF VEHICLES)	PHOENIX	HOUSTON	LOS ANGELES	DENVER	TOTALS
RELIABILITY AFFECTED, ONLY	0	0	3	0	3
READINESS AFFECTED, ONLY	2	17	10	9	38
RELIABILITY & READINESS AFFECTED	0	1	0	0	1
NO PROBLEMS; SYSTEMS IN USE	8	44	39	24	115
SYSTEMS NEVER USED	0	3	5	2	10
VEHICLE HAS BEEN SOLD	(17)*	(43)*	(17)*	(26)*	(103)*
NO CONTACT OR RESPONSE	(37)*	(26)*	(68)*	(50)*	(181)*
TOTALS	*	*	*	*	*

*Totals in parenthesis reflect combined totals for manual and automatic VW Rabbit systems.

Failure
Analysis
Associates
FAA-82-2-14

TABLE 3.7

Summary Of Hardware Identification Program
Phoenix Metropolitan Area

	PHOENIX	Chevette	Corona							Rabbit (Man.)				Rabbit (Auto.)				TOTAL
		76	74	75	76	77	78	79	Tot.	75	76	79	Tot.	75	76	79	Tot.	
RELIABILITY AFFECTED	[a]REPORTED NO. OF VEHICLES	6	0	1	0	1	1	1	4	0	5	1	6	0	0	0	0	16
	REPORTED NO. OF INCIDENCES	7	0	1	0	1	1	1	4	0	5	2	7	0	0	0	0	18
	A. Webbing Failure	1	0	0	0	0	0	1	1	0	0	1	1	0	0	0	0	3
	B. Buckle Failure	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0	2
	C. Tongue Failure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D. Retractor Failure	6	0	1	0	0	1	0	2	0	4	0	4	0	0	0	0	12
	E. Floor Mount Failure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F. Other	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1
READINESS AFFECTED	[b]REPORTED NO. OF VEHICLES	11	3	5	8	3	4	9	32	0	10	18	28	0	0	2	2	73
	REPORTED NO. OF INCIDENCES	16	4	5	12	4	6	13	44	0	14	22	36	0	0	6	6	102
	G. Slow/Sticky Retractor	3	0	0	0	0	1	0	1	0	0	1	1	0	0	0	0	5
	H. Guide Ring Failure	0	0	1	2	0	0	1	4	0	0	0	0	0	0	0	0	4
	I. Adjusting Ring Failure	0	0	0	2	0	1	0	3	0	1	0	1	0	0	0	0	4
	J. Belt Twisting/Knotting	4	2	0	0	0	0	2	4	0	3	3	6	0	0	0	0	14
	K. Belt Catching in Door	3	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	4
	L. Difficulty Adjusting	0	0	0	0	1	0	0	1	0	0	3	3	0	0	1	1	5
	M. Latch Problems	1	0	0	1	0	0	0	1	0	0	0	0	0	0	1	1	3
	N. Belt too Tight	2	0	0	1	0	1	1	3	0	1	3	4	0	0	1	1	10
	O. Difficulty Reaching Belt	1	1	0	3	1	1	4	10	0	5	4	9	0	0	0	0	20
	P. Belt Poorly Positioned	1	1	3	2	0	2	4	12	0	4	4	8	0	0	2	2	23
	Q. Frayed/Torn Webbing	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	2
	R. Other	0	0	1	1	2	0	1	5	0	0	2	2	0	0	1	1	8
[c]REPORTED NO. OF VEHICLES WITH SUCCESSFUL SYSTEM USAGE		10	3	3	10	15	13	7	51	3	4	11	18	0	2	6	8	87
[d]REPORTED NO. OF VEHICLES WITH UNUSED SYSTEMS		5	1	0	5	1	7	5	19	1	4	3	8	0	0	0	0	32
[e]VEHICLES REPORTING BOTH RELIABILITY AND READINESS PROBS.		4	0	1	0	0	1	0	2	0	3	0	3	0	0	0	0	9
TOTAL VEHICLES REPORTED a + b + c + d - e		28	7	8	23	20	24	22	104	4	20	33	57	0	2	8	10	199

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TABLE 3.8

Summary of Hardware Identification Program
Houston Metropolitan Area

	HOUSTON	Chevette	Corona							Rabbit (Man.)				Rabbit (Auto.)				TOTAL
		76	74	75	76	77	78	79	Tot.	75	76	79	Tot.	75	76	79	Tot.	
RELIABILITY AFFECTED	[a]REPORTED NO. OF VEHICLES	4	2	1	2	2	0	2	9	2	0	0	2	1	0	0	1	16
	REPORTED NO. OF INCIDENCES	4	2	1	3	2	0	2	10	2	0	0	2	1	0	0	1	17
	A. Webbing Failure	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
	B. Buckle Failure	2	0	0	1	1	0	0	2	0	0	0	0	1	0	0	1	5
	C. Tongue Failure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D. Retractor Failure	2	1	1	2	0	0	2	6	2	0	0	2	0	0	0	0	10
	E. Floor Mount Failure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F. Other	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1
READINESS AFFECTED	[b]REPORTED NO. OF VEHICLES	13	8	0	14	14	9	7	52	3	7	4	14	2	2	14	18	97
	REPORTED NO OF INCIDENCES	14	11	0	16	16	10	9	62	4	8	5	17	2	3	16	21	114
	G. Slow/Sticky Retractor	11	5	0	2	3	1	5	16	0	2	0	2	2	1	10	13	42
	H. Guide Ring Failure	0	2	0	2	1	1	0	6	0	0	1	1	0	0	0	0	7
	I. Adjusting Ring Failure	0	0	0	2	0	0	0	2	1	0	0	1	0	0	0	0	3
	J. Belt Twisting/Knotting	0	2	0	0	0	0	0	2	1	1	4	6	0	1	0	1	9
	K. Belt Catching in Door	1	0	0	1	0	0	1	2	0	0	0	0	0	0	0	0	3
	L. Difficulty Adjusting	0	1	0	2	2	1	1	7	0	0	0	0	0	1	0	1	8
	M. Latch Problems	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	1
	N. Belt too Tight	0	0	0	1	0	2	1	4	0	1	0	1	0	0	2	2	7
	O. Difficulty Reaching Belt	0	1	0	1	6	0	0	8	0	1	0	1	0	0	0	0	9
	P. Belt Poorly Positioned	0	0	0	3	2	3	1	9	1	2	0	3	0	0	3	3	15
	Q. Frayed/Torn Webbing	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1
	R. Other	2	0	0	1	1	2	0	4	1	1	0	2	0	0	1	1	9
[c]REPORTED NO. OF VEHICLES WITH SUCCESSFUL SYSTEM USAGE		50	23	22	40	37	57	46	225	16	15	22	53	4	13	27	44	372
[d]REPORTED NO. OF VEHICLES WITH UNUSED SYSTEMS		21	7	7	21	19	15	32	101	3	9	14	26	0	0	3	3	151
[e]VEHICLES REPORTING BOTH RELIABILITY AND READINESS PROBS.		0	0	0	1	1	0	0	2	1	0	0	1	1	0	0	1	4
TOTAL VEHICLES REPORTED a + b + c + d - e		88	40	30	76	71	81	87	385	23	31	40	94	6	15	44	65	632

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TABLE 3.9

Summary of Hardware Identification Program
Los Angeles Metropolitan Area

	LOS ANGELES	Chevette	Corona							Rabbit (Man.)				Rabbit (Auto.)				TOTAL
		76	74	75	76	77	78	79	Tot.	75	76	79	Tot.	75	76	79	Tot.	
RELIABILITY AFFECTED	[a]REPORTED NO. OF VEHICLES	1	7	0	1	2	0	1	11	1	1	1	3	0	0	3	3	18
	REPORTED NO. OF INCIDENCES	1	7	0	1	2	0	1	11	1	1	1	3	0	0	3	3	18
	A. Webbing Failure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B. Buckle Failure	0	1	0	0	1	0	0	2	0	0	0	0	0	0	0	0	2
	C. Tongue Failure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D. Retractor Failure	1	5	0	1	1	0	1	8	1	1	1	3	0	0	2	2	14
	E. Floor Mount Failure	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
	F. Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
READINESS AFFECTED	[b]REPORTED NO. OF VEHICLES	7	21	6	9	8	13	13	70	11	7	6	24	1	1	8	10	111
	REPORTED NO. OF INCIDENCES	11	33	7	13	9	16	16	94	15	11	6	32	1	1	13	15	152
	G. Slow/Sticky Retractor	3	6	0	2	1	2	4	15	2	5	1	8	0	0	4	4	30
	H. Guide Ring Failure	0	4	1	3	0	2	0	10	0	0	0	0	0	0	0	0	10
	I. Adjusting Ring Failure	0	0	1	1	0	0	0	2	0	0	0	0	0	0	0	0	2
	J. Belt Twisting/Knotting	0	3	1	0	0	1	0	5	1	0	1	2	0	0	0	0	7
	K. Belt Catching in Door	0	0	0	0	0	0	2	2	1	0	0	1	0	0	1	1	4
	L. Difficulty Adjusting	3	6	0	2	0	1	0	9	3	1	0	4	0	0	2	2	18
	M. Latch Problems	0	0	1	0	0	0	0	1	0	1	1	2	0	0	0	0	3
	N. Belt too Tight	1	1	1	1	1	2	2	8	0	0	1	1	0	0	1	1	11
	O. Difficulty Reaching Belt	1	5	1	3	5	2	1	17	4	3	1	8	0	0	0	0	26
	P. Belt Poorly Positioned	3	3	1	0	1	4	4	13	3	0	1	4	0	1	0	1	21
	Q. Frayed/Torn Webbing	0	4	0	0	0	1	0	5	1	0	0	1	0	0	1	1	7
	R. Other	0	1	0	1	1	1	3	7	0	1	0	1	1	0	4	5	13
[c]REPORTED NO. OF VEHICLES WITH SUCCESSFUL SYSTEM USAGE		16	20	6	21	23	31	43	144	6	17	9	32	1	13	25	39	231
[d]REPORTED NO. OF VEHICLES WITH UNUSED SYSTEMS		7	5	4	7	11	11	12	50	1	2	1	4	2	1	2	5	66
[e]VEHICLES REPORTING BOTH RELIABILITY AND READINESS PROBS.		1	5	0	0	0	0	1	6	0	0	1	1	0	0	0	0	8
TOTAL VEHICLES REPORTED a + b + c + d - e		30	48	16	38	44	55	68	269	19	27	16	62	4	15	38	57	418

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TABLE 3.10

Summary of Hardware Identification Program
Denver Metropolitan Area

	OENVER	Chevette	Corona							Rabbit (Man.)				Rabbit (Auto.)				TOTAL
		76	74	75	76	77	78	79	Tot.	75	76	79	Tot.	75	76	79	Tot.	
RELIABILITY AFFECTED	[a]REPORTED NO. OF VEHICLES	3	3	4	4	0	0	0	11	1	4	0	5	0	0	0	0	19
	REPORTED NO. OF INCIDENCES	6	3	4	4	0	0	0	11	1	4	0	5	0	0	0	0	22
	A. Webbing Failure	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	B. Buckle Failure	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	2
	C. Tongue Failure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	O. Retractor Failure	2	3	4	4	0	0	0	11	1	3	0	4	0	0	0	0	17
	E. Floor Mount Failure	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	F. Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
READINESS AFFECTED	[b]REPORTED NO. OF VEHICLES	30	18	6	7	9	6	1	47	7	19	0	26	0	8	1	9	112
	REPORTED NO. OF INCIDENCES	67	29	10	7	10	7	1	64	11	25	0	36	0	8	1	9	176
	G. Slow/Sticky Retractor	22	3	3	2	0	1	0	9	3	5	0	8	0	0	1	1	40
	H. Guide Ring Failure	3	2	0	0	0	0	0	2	0	1	0	1	0	0	0	0	6
	1. Adjusting Ring Failure	1	0	1	1	1	0	0	3	0	0	0	0	0	0	0	0	4
	J. Belt Twisting/Knotting	6	8	1	0	2	2	0	13	2	3	0	5	0	1	0	1	25
	K. Belt Catching in Door	3	2	0	0	0	0	0	2	0	2	0	2	0	0	0	0	7
	L. Difficulty Adjusting	4	5	0	0	0	1	1	7	1	0	0	1	0	0	0	0	12
	M. Latch Problems	2	0	0	1	0	0	0	1	0	1	0	1	0	0	0	0	4
	N. Belt too Tight	3	2	1	0	1	0	0	4	1	2	0	3	0	3	0	3	13
	O. Difficulty Reaching Belt	8	1	0	1	3	1	0	6	0	1	0	1	0	0	0	0	15
	P. Belt Poorly Positioned	9	4	3	2	3	2	0	14	3	7	0	10	0	2	0	2	35
	Q. Frayed/Torn Webbing	3	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0	5
	R. Other	3	1	0	0	0	0	0	1	1	3	0	4	0	2	0	2	10
[c]REPORTED NO. OF VEHICLES WITH SUCCESSFUL SYSTEM USAGE		25	13	12	20	22	18	7	92	3	22	2	27	1	18	5	24	168
[d]REPORTED NO. OF VEHICLES WITH UNUSED SYSTEMS		13	2	2	8	12	0	4	28	0	8	1	9	0	2	0	2	52
[e]VEHICLES REPORTING BOTH RELIABILITY AND READINESS PROBS.		3	1	1	1	0	0	0	3	0	1	0	1	0	0	0	0	7
TOTAL VEHICLES REPORTED a + b + c + d - e		68	35	23	38	43	24	12	175	11	52	3	66	1	28	6	35	344

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4.0 TASK 3 - EXPERIMENTAL STUDY OF SEAT BELT DEGRADATION AND COMPONENT TESTING

Efforts in Task 3 identified those components having obvious impact on belt system reliability. Subsequently, secondary contact with vehicle owners was accomplished in an attempt to procure systems being considered for component testing. In addition, new replacement belt systems for Rabbit, Chevette, and Corona manual and automatic designs were procured for nondegraded (new) baseline strength testing. Such preliminary baseline strength testing was conducted and a procedure for testing the various used belt system components was developed.

4.1 MANUAL AND AUTOMATIC BELT SYSTEM PROCUREMENT

As was shown in Figure 1.1 the methodology for reliability analysis of seat belt systems involved component strength testing of used systems with obvious failures and systems which appeared satisfactory. To define the reliability as a function of age, procurement of specimens with varying ages, including new systems was required.

The procurement of new manual and automatic systems was accomplished through parts departments at the appropriate dealerships. Original orders placed by FAA included two manual and one automatic system for each of the three vehicles, Rabbit, Chevette, and Corona. The costs of the manual and automatic systems for Rabbit and Chevette were between approximately $125 - $200 each, as was the Toyota manual system. However, the Toyota automatic system which employs an

electric motor gear and rack system had a purchase price of approximately $1000 for just the passenger system. Furthermore, this cost did not includes the microcomputer system which controls the electric belt system in addition to other functions within the vehicle.

The procurement of used systems is discussed in Section 3.3

FAA experienced very little cooperation on the part of vehicle owners in the used belt system replacement program. Most owners expressed little interest in having even faulty systems replaced and all but two of some 200 owners whose systems were working properly would not consent to a belt system exchange. Some expressed the desire to receive personal remuneration to replace satisfactory systems, but FAA considered these requests prohibitive due to budgetary constraints.

Unfortunately, this lack of cooperation reduced sampling methodology to procurement of forty-one (41) systems with an obviously failed or degraded component and only two systems apparently operating satisfactorily. In addition, two new replacement belt systems for Toyoto Corona were added to the two Toyota systems previously ordered for baseline component testing because the owner refused to have the belts installed after FAA had made the replacement appointment.

Since the Reliability analysis as designed by FAA considers individual component reliabilities, each belt system procured provides useful information. Even though most of the systems obtained possessed one failed component, the remaining unfailed

components provide information relating to the effects of degradation and use. FAA assumed no component coupling affects, i.e.; one component failure accelerating the wear or failure rate of adjacent components.

4.2 BELT SYSTEM COMPONENT STRENGTH TESTING

To determine the effect of degradation or use on the reliability of manual and automatic seat belt systems, it is necessary to establish both baseline (new) component strengths and any reduction in strength of used components. To accomplish this, FAA developed a testing sequence employing FMVSS No. 209 type test procedures. The intent of the component testing for reliability analysis is to establish component ultimate strengths thereby defining the maximum load each respective component could support without failure. The component strength testing was conducted in FAA's Los Angeles laboratory utilizing an MTS closed-loop, servohydraulic testing machine shown in Figure 4.1. An X-Y Plotter is used for data recording, an example of which is shown in Figure 4.2. Unless otherwise stated, all components were pulled to failure in the same manner, that is preloaded to 1500 lbs. and then loaded to failure at an extension rate of three (3) inches per minute.

4.2.1 Chevrolet Chevette Manual System

Figure 4.3 shows a representation of the manual seat belt system found in 1976 Chevrolet Chevettes. The annotation of components within the system was chosen by FAA and represents

consistent nomenclature to be used throughout this report. Of interest is the identification of both the buckle and tongue as "buckle". This was chosen because any strength testing associated with the buckle or buckle assembly requires inclusion of the tongue to transfer load within the system. Therefore a failure of the buckle suggests separation of the buckle and tongue.

Within the buckle assembly, the buckle webbing and buckle assembly floor attachment are considered as separate components. In addition, the continuous webbing, which serves as both torso and pelvic restraint as shown in Figure 4.3 is considered a single component "webbing". The remaining components distinguished within this Chevette manual belt system are the retractor and secondary floor attachment.

The procedure for testing the Chevette manual belt system components is described as follows:

1. Floor Attachment Fitting Test.

   Webbing was cut approximately two (2) feet from the secondary floor attachment fitting. The attachment fitting was bolted to fixture plate using FAA supplied bolts. The two foot webbing section was wrapped around the split drum fixture mounted on the MTS machine. The assembly, is shown in Figure 4.4. Note that Figure 4.4 is a photograph of a used 1976 Chevette manual belt component, but the Figure applies to both new and used components.

2. Retractor Latch Test

The webbing within the retractor was extended completely and subsequently allowed to retract approximately two to three turns of the retractor wheel. From this point, an additional two (2) foot length was retained with the extraneous webbing being removed by cutting. The retractor was then bolted to a fixture plate in an orientation such that the loading on the webbing was in approximately the same direction as found *in situ*. The two (2) foot webbing section was wrapped around the fixed drum fixture and loaded in the MTS machine at an extension rate of three (3) inches per minute to failure. An example of the test setup is shown in Figure 4.5.

3. Buckle Assembly Test

A four (4) foot length of webbing remaining after sectioning for the floor attachment fitting and retractor testing described above was passed through the tongue and wrapped (double webbing) around the split drum fitting. The tongue was then inserted into the buckle and the buckle assembly floor attachment fitting was bolted to the MTS fixture plate. Figure 4.6 shows an example of the test configuration.

Due to the incorporation of independent webbing testing discussed below, and the finite length of webbing in any one system, certain tests used exemplar webbing during

buckle assembly testing.

4. Webbing Test

Approximately four (4) feet of webbing was removed from the retractor for webbing testing in accordance with FMVSS No. 209, S5.1. The grips were four (4) inch diameter split drum fixtures, with the webbing initially loaded to 50 lbs. and extensometer needles were inserted through the center of the webbing approximately five (5) inches apart, and the measurement recorded. The webbing was preloaded to 2000 lbs. and then extended at three (3) inches per minute until the load reached 2500 lbs. The extension was then halted for approximately ten (10) seconds and the extension was recorded. In all test cases, the elongation was 20 percent or less at 2500 lb. load.

4.2.2 Chevrolet Chevette Automatic System

Figure 4.7 shows a representation of the automatic seat belt system offered as an option in 1980 Chevrolet Chevettes. The piller interlock of the Chevette automatic belt system as shown in Figure 4.7, performs a similar function as the Chevette manual system secondary floor attachment, shown in Figure 4.3. Design differences preclude the use of floor

attachment degradation for the piller interlock. This component was not tested because of the difficulty in properly replicating the door attachment geometry. It was not considered in the reliability analysis conducted in Task 4, and thus makes that analysis an "upperbound".

1. Retractor Latch Test

   The dual retractor design employed in the Chevette automatic belt system is also shown in Figure 4.7. This unique design required testing of individual retractors only as the fixtures available with the MTS machine could not accommodate dual systems. The procedure involved bolting the retractor to a fixture, and wrapping the webbing around the split drum fixture, and pulling to failure. This procedure repeats that used for manual retractors.

2. Buckle Assembly Test

   A section of webbing two (2) feet from the tongue was required to wrap around the split drum fixture. The tongue was then inserted into the emergency buckle and the buckle attachment was bolted to a fixture plate. Following this setup, the buckle was preloaded and extended at a rate of three (3) inches per minute until failure occurred.

   Figure 4.7 also shows a child's buckle which is to be

utilized for children or small adults. This component was not tested and was not considered in the reliability analysis conducted in Task 4.

4.2.3 Toyota Corona Manual Belt System 1974-1978 Model Years

Figure 4.8 shows a representation of the manual belt system found in 1974-1978 Toyota Coronas.

This belt system differs from the Chevette system with separate shoulder (torso) webbing and lap (pelvic) webbing each individually sewn at the tongue. In addition, there are separate shoulder and lap retractors. Since the testing procedure and equipment could not accommodate testing the entire system simultaneously, the shoulder webbing was separated at the tongue sewn joint and the shoulder assembly was tested independently.

1. Shoulder Retractor/Webbing Test

   The shoulder webbing was separated at the sewn joint at the tongue. The shoulder webbing was then wrapped around the split drum fixture and the shoulder retractor was bolted to a fixture plate. Figure 4.9 shows an example of this test arrangement.

2. Retractor-Webbing-Buckle Assembly Test

   After the shoulder webbing was separated from the tongue, the remaining retractor-webbing-buckle assembly could be

loaded simultaneously. This required bolting the retractor to one fixture plate, inserting the tongue into the buckle, and bolting the buckle assembly floor attachment to another fixture. Figure 4.10 shows this test configuration.

The components which did not fail were subsequently tested to failure according to procedures listed below.

3. Retractor Latch Test

If the buckle assembly or webbing at the tongue sewn joint failed in Test (2) above, the retractor latch was subsequently tested to failure. The procedure requires removing the tongue from the webbing, wrapping the webbing around the split drum fixture, and bolting the retractor to a fixture plate. An example of this experimental equipment is shown in Figure 4.11.

4. Buckle Assembly Test

If the retractor latch or webbing failed in Test (2) above, the assembly was subsequently tested to failure. If the retractor latch failed first, the remaining webbing was wrapped around the split drum fixture, the tongue was inserted into the buckle, and the buckle assembly was bolted to a fixture plate. However, if the webbing failed at the tongue sewn joint, a pin and clevis fixture was attached to the tongue and used to load the buckle assembly to failure.

4.2.4 Toyota Corona Manual Belt System 1979 Model Year

Figure 4.12 shows a representation of the 1979 Toyota Corona manual belt system. This design differs from the manual system discussed in the previous section in the utilization of dual webbing sections, one torso and one pelvic restraint opposed to separate pelvic and torso retractors.

1. Retractor Latch Test

   To conduct the retractor latch test, both sections of webbing were sectioned between the retractor and tongue. A two (2) foot (double thick) section was retained for the buckle assembly test. The remaining dual belt was wrapped around the split drum fixture and the retractor was bolted to a fixture plate.

2. Buckle Assembly Test

   The four (4) foot (two (2) foot double thick) webbing section was passed through the tongue and wrapped around the split drum fixture (both ends). Figure 4.13 shows an example of this test configuration.

4.2.5 Toyoto Corona Automatic Belt System

Figure 4.14 depicts the Toyota Corona 1980 model year automatic torso belt system and manual pelvic belt system. This system employs a unique electric motor driven rack and gear drive system to move the torso webbing along a guide rail atop the door frame. A microcomputer controls the system

actuation utilizing limit switches, and an emergency lock is included to prevent complete system failure during a collision should the rack fail.

Due to the complexity of this unique design, the expense for one passenger's side system, minus the microcomputer, was approximately $1,000. This expense prohibited the purchase of more than one system for analysis. Since one system is insufficient to provide statistical validity to component strength tests none were conducted. However, inspection of the system components will allow a reliability analysis to be conducted for this system in Task 4 utilizing information gathered for equivalent components found in manual systems. Those components not common to Toyota manual belt systems will be assumed to not affect the reliability, making this valve an upper bound.

As discussed in Task 2, FAA did research information regarding electric motor reliability. This information will be discussed in Task 4 as it related to Toyota automatic belt system restraint readiness.

4.2.6 Volkswagen Rabbit Manual Belt System

Figure 4.15 shows a representation of the Volkswagen Rabbit manual belt system. This system is very similar to the Chevette manual belt system discussed in Section 4.2.1. One notable difference is the use of a cable within the buckle assembly.

1. Secondary Floor Attachment Fitting Test

The webbing was first severed approximately two (2) feet from the attachment fitting. The attachment fitting was then bolted to a fixture plate and the webbing was wrapped around the split drum fixture. Figure 4.16 shows this testing configuration.

2. Webbing Test

The procedure employed to determine webbing strength independent of sewn joint effects was in accordance with FMVSS No. 290, S 5.1, as previously discussed in Section 5.2.1 of this report concerning similar testing of Chevette webbing. The breaking strength was determined by removing a four (4) foot section of webbing from the retractor, wrapping it around two split drum fixtures, preloading, measuring the percent elongation, and then loading to failure at an extension rate of three (3) inches per second. In all cases tested, the elongation was 20 percent or less 2500 lb. load.

3. Retractor Latch Test

The webbing remaining on the retractor was extended approximately two (2) feet and wrapped around the split drum fixture. The retractor was then bolted to a fixture plate and the assembly was preloaded to approximately 1500 lbs. as shown in Figure 4.17 . Completion of the testing

extended the assembly at a rate of three (3) inches per minute until failure occurred.

4. Buckle Assembly Test

Since the webbing was used to determine webbing strength and percent elongation as previously discussed, the buckle assembly test procedure required the use of a pin and clevis to apply load to the tongue. This clevis was bolted to a fixture plate with the tongue being inserted into the buckle. The buckle assembled floor attachment was bolted to another fixture plate as shown in Figure 4.18, and tested. An example of a buckle assembly failure in which the tongue fractured at approximately 5950 lb. load is shown in Figure 4.19.

4.2.7 Volkswagen Rabbit Automatic Belt System

The Rabbit automatic belt system is shown in Figure 4.20. This system employs a floor mounted retractor, torso webbing, and an emergency buckle attached to the door. A unique feature of the Rabbit system is the incorporation of a padded knee bolster below the dashboard to provide pelvic restraint. Upon vehicle frontal impact, the occupant's knees contact the bolster and transfer the load through the femurs and hips.

1.Retractor Latch Test

The webbing was sectioned approximately two (2) feet and six (6) feet from the buckle end. The remaining webbing was wrapped around the split drum fixture, and the retractor was bolted to a fixture plate. The system, as shown in Figure 4.21 was then loaded to failure.

2.Webbing Test

The four (4) foot webbing piece was wrapped around two split drum fixtures and tested according to FMVSS No. 209, S 5.1, as discussed in Section 4.2.1.

This process involves preloading the webbing, measuring the percent elongation, and then loading to failure at a rate of three (3) inches per minute.

3.Buckle Assembly Test

The buckle assembly for the Rabbit automatic belt system was tested in two ways. First, the two (2) foot section of webbing, including the buckle, was wrapped around the split drum fixture, the tongue was inserted into the buckle assembly, and the buckle was bolted to an angled fixture plate (Figure 4.22) to simulate the loading configuration in the vehicle. The assembly was preloaded to approximately 1500 lbs. and subsequently loaded to failure.

In most cases, the webbing failed at the tongue sewn joint so a second test procedure was developed using a pin and clevis fixture to transfer load to the buckle assembly. This test setup is shown in Figure 4.23.

4.2.8 Test Results

A summary of the test results identifying the minimum strengths data recorded for each component is shown in Table 4.1. Minimum strengths for particular components are used because they represent the maximum loads the component can withstand.

The results of the component strength testing are shown in Appendix L. Each test sheet represents one belt system and the serial number at the top of each page was assigned by FAA for organizational purposes. The individual tests identified were discussed previously and the sequence in which the tests were conducted is numbered. The failure location identifies which particular components failed during testing and the load at failure is shown. Any additional information, including the elongation testing, is shown under "Notes or Comments".

4.2.9 Computation of Loading Factors for Seat Belt Components

The different types of seat belt systems have been identified in terms of a common set of components. A typical load distribution was computed based on an assumed unit (one pound) tension in the torso belt for each system. Many of the components are simply connected in series with the torso belt,

so in service see the same load as the belt (loading factor, 1.0).

In systems where a lap belt meets the torso belt (as at a buckle) the vector sum of the two loads was calculated based on an approximated angle of 60° based on system geometry, between the two belts. Then for equal loads in the two belts, the flexibility of the system will permit the junction to become oriented such that each belt lies 30° off the line of action of the third part (e.g., buckle assembly) of the junction.

For the above case the loading factor for the buckle assembly is computed as follows:

$$T_{\text{buckle assembly}} = T_{\text{torso belt}} \cos 30^0 + T_{\text{lap belt}} \cos 30^0 = 1.7$$

Similar computations were made for all of the systems. These loading factors appear at the top of Table 5.9 for each seat belt design. Calculations are shown in Appendix M for two example cases.

4.3 RETRACTOR ENGAGEMENT/ACCELERATION TESTING

The function of a retractor within a seat belt system is two-fold. First, the retractor allows convenient storage of webbing when not in use and provides a means of adjustment for occupants of varying sizes. Second, it provides an attachment point and locking mechanism to react loading of the belt system during vehicle collision. To accomplish the second function, the retractor must possess a means of locking the retracting spool during vehicle impact.

The two basic design configurations utilized for the retractor locks considered in this project include a pendulum locking mechanism which is sensitive to vehicle (or retractor) acceleration and an inertial wheel clutch mechanism which is sensitive to belt extension rate and angular acceleration of the retracting spool.

FMVSS No. 209, S 4.3, requires that the retractor locking mechanism be capable of engaging before the webbing extends one (1) inch when the retractor is subjected to an acceleration of 0.7g. The actual acceleration of the retractor upon a 29.4 mph frontal impact could not be obtained from the crash data supplied by the NHTSA so the .7g level was used as an approximation for preliminary analysis. FAA therefore designed an acceleration test bench which could affect a .7g acceleration upon the retractor to test the effectiveness of both locking mechanisms together as a single retractor unit. The bench is depicted in Figure 4.24. Note the linear displacement which monitors the linear position of the cart. The potentiometer was used to monitor the displacement of the cart as a function of time from which the acceleration was calculated using the expression

$$S = V_0 t + \tfrac{1}{2} a t^2$$

where

S = Distance travelled (inches)

V_0 = Initial Velocity = 0

a = Acceleration (in/sec^2)

t = time (seconds)

Solving for the acceleration in g's (386 in/sec^2)

$$a = \frac{2s}{386t^2} \text{ g's}$$

The displacement, as a function time, was recorded using a Hewlett Packard 5423A Structural Dynamics Analyzer located in the FAA Phoenix Laboratory.

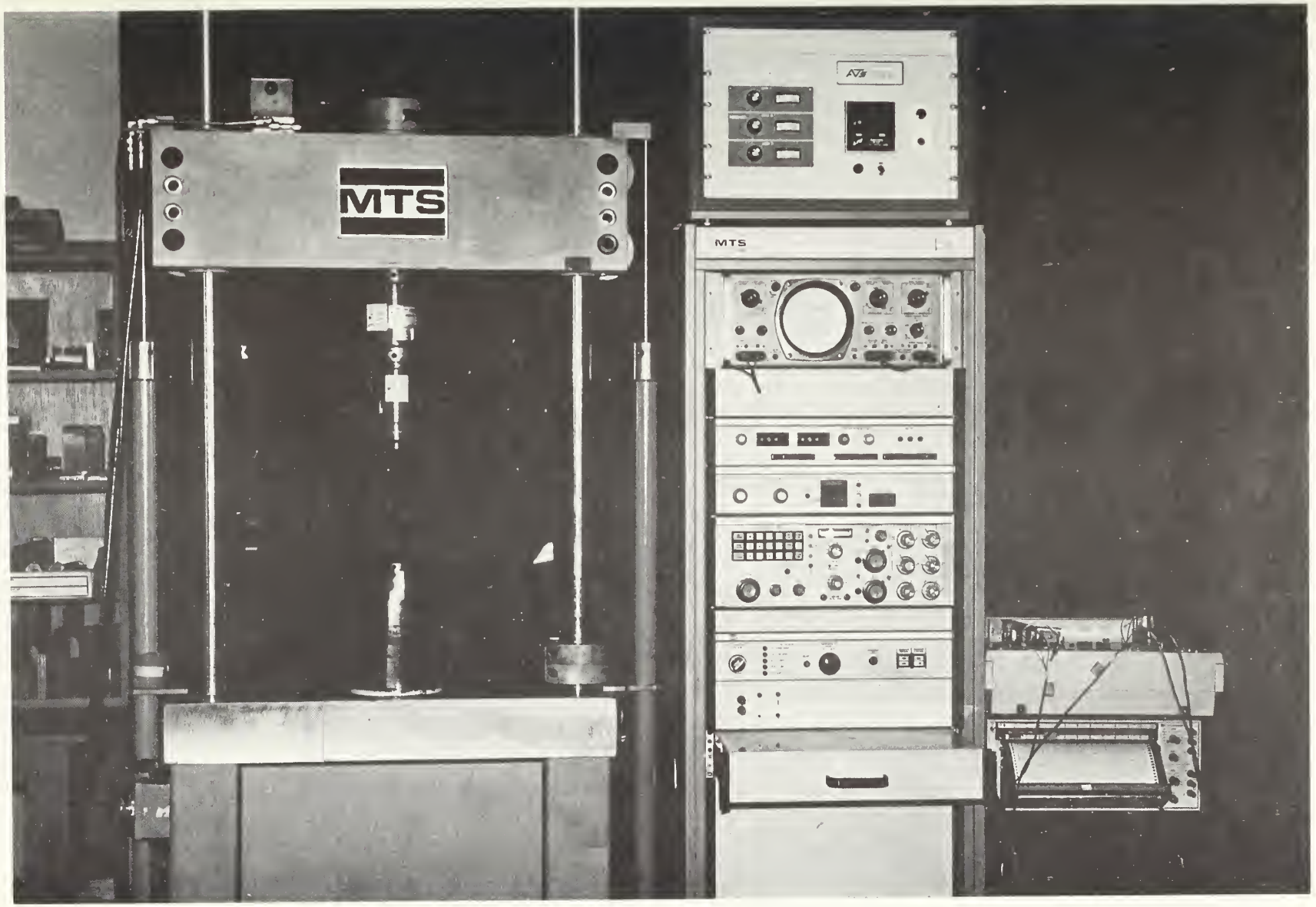

Figure 4.1 - MTS Closed-Loop Servohydraulic Testing Machine.

1976 Chevette
VIN: 1B08E6Y242968

Drivers-Side Seat Belt

Buckle Assembly

3 Inches per Minute Stroke Rate

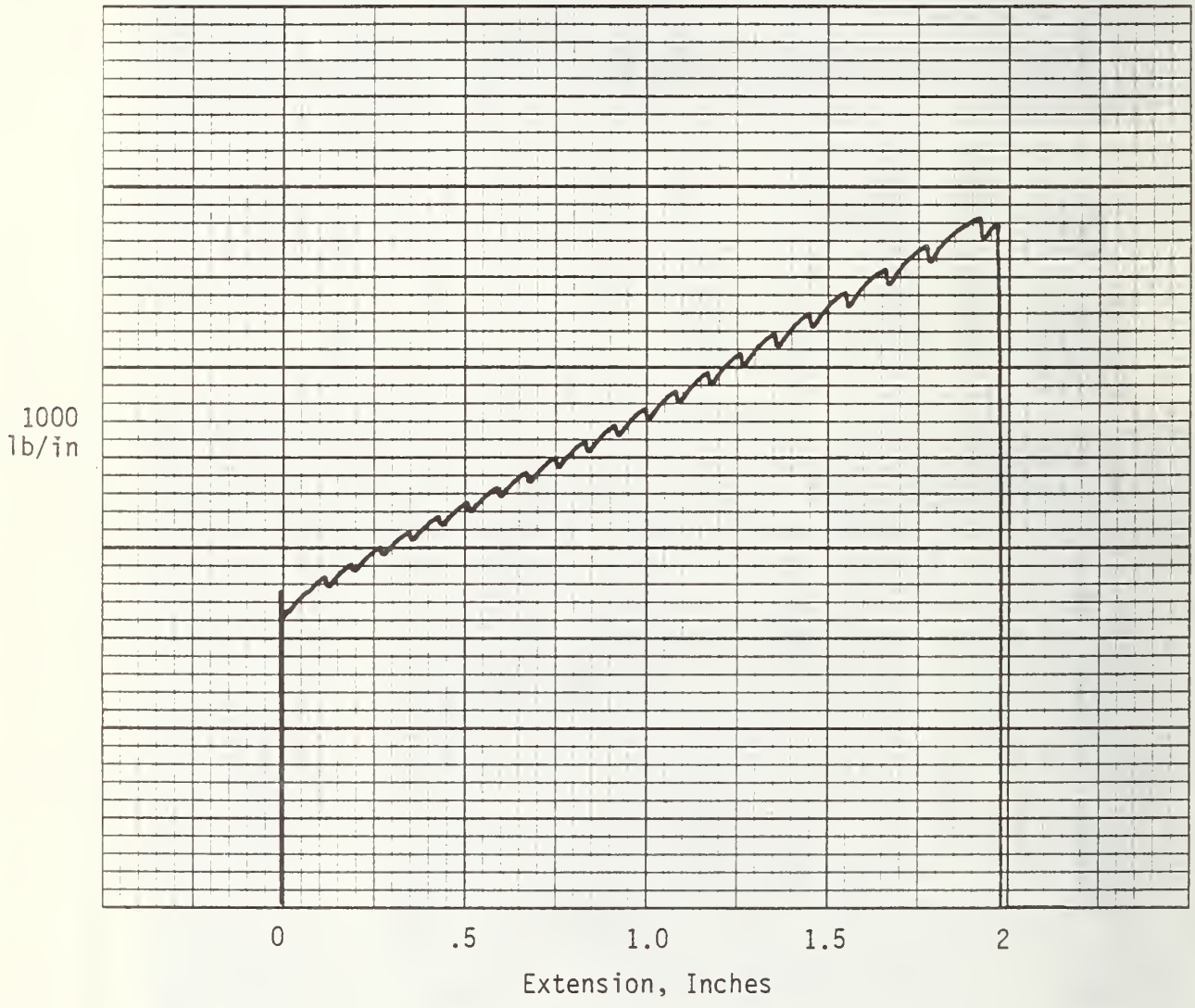

Figure 4.2 - Example of MTS Machine X-Y Recorder Plot.

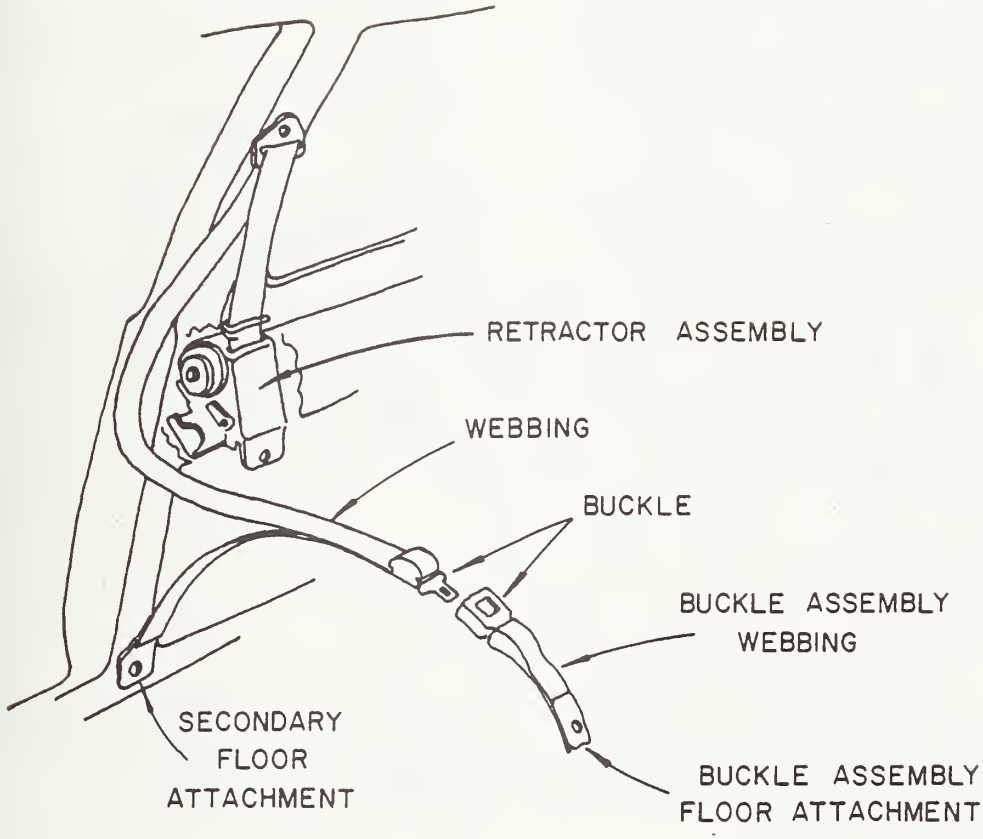

Figure 4.3 Chevrolet Chevette
Manual Seat Belt System
Passenger's Side

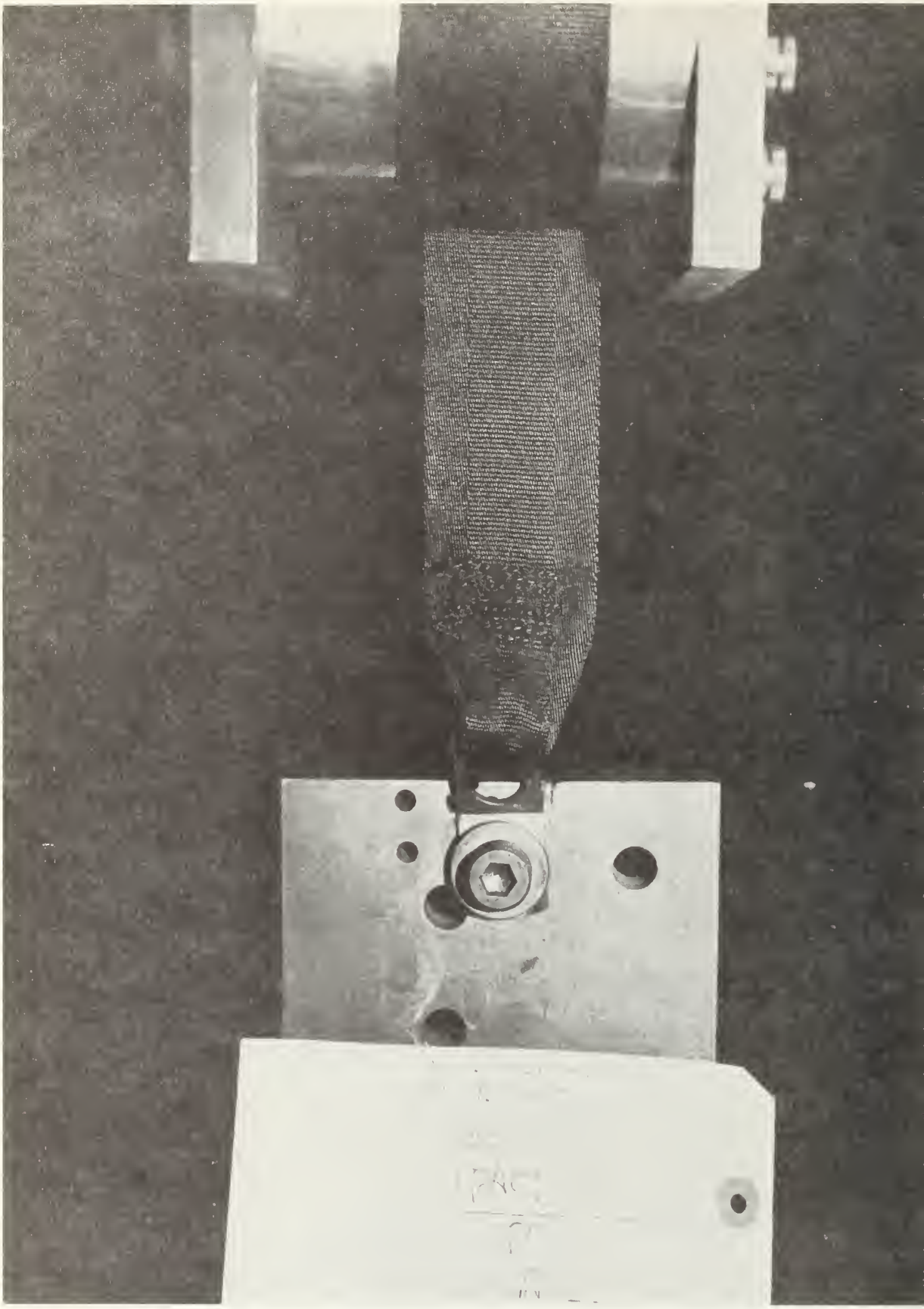

Figure 4.4 - Floor Attachment Fitting Test - 1976 Chevette Manual Seat Belt.

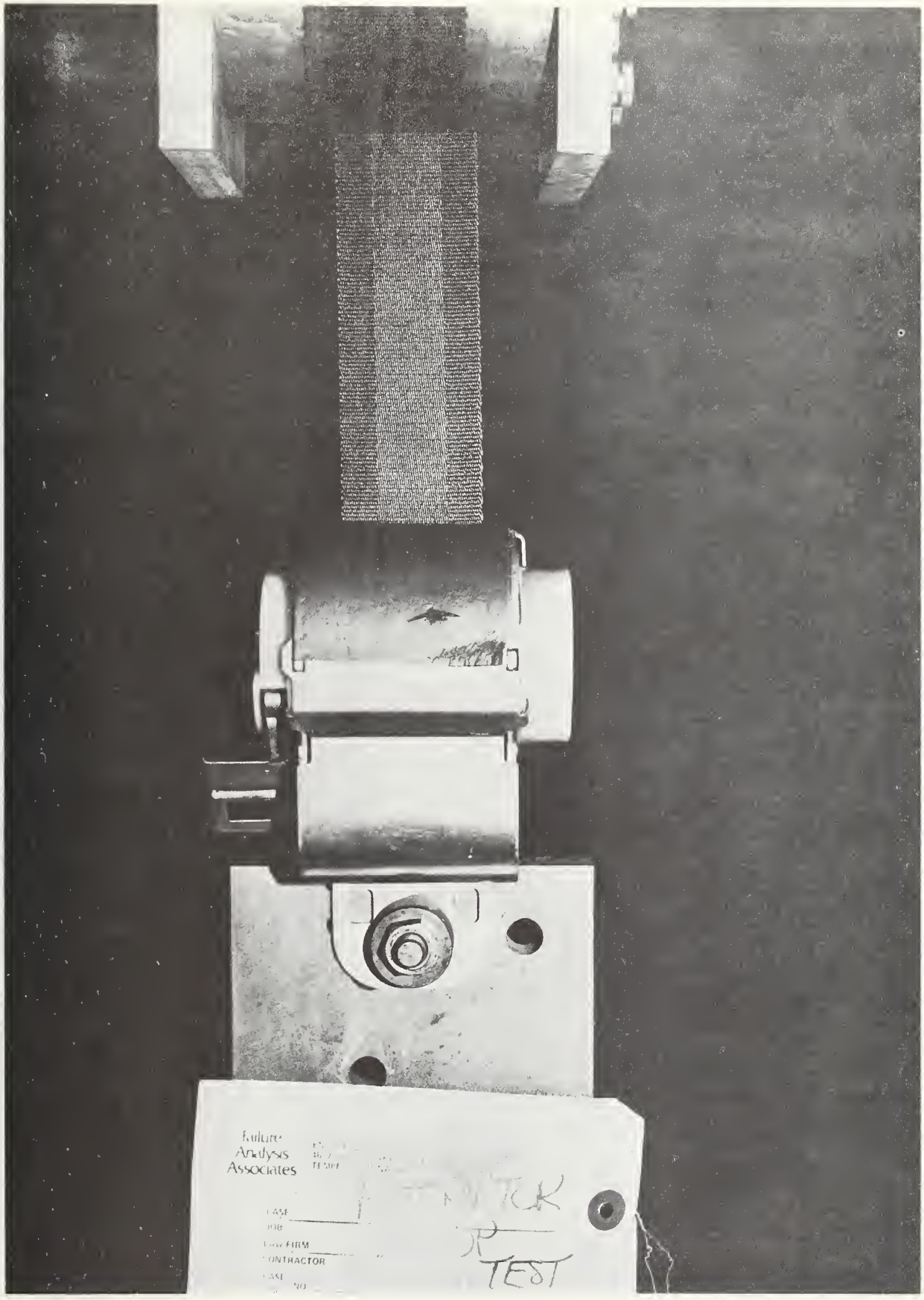

Figure 4.5 - Retractor Latch Test - 1976 Chevette Manual Seat Belt System.

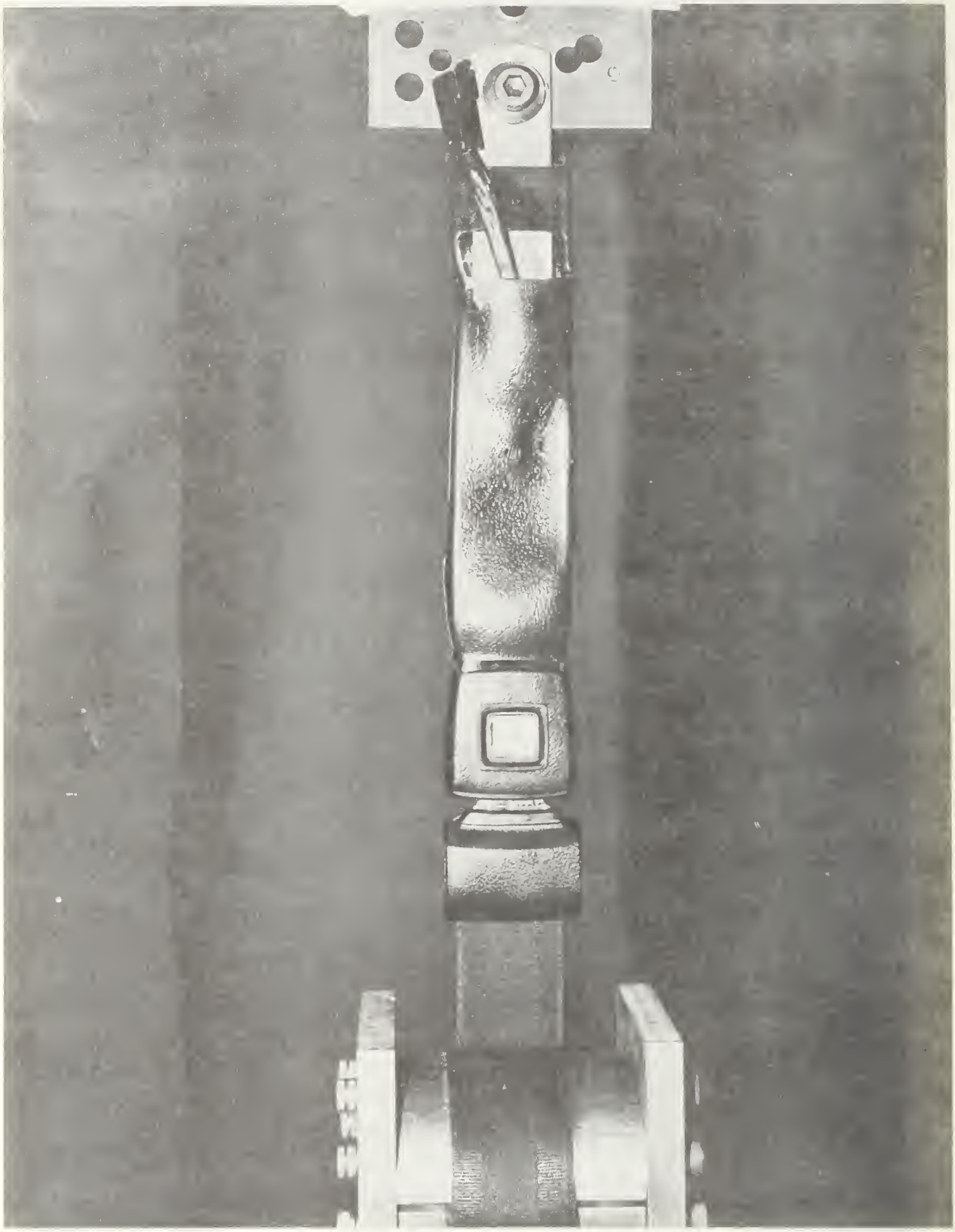

Figure 4.6 - Buckle Assembly Test - 1976 Chevette Manual Seat Belt System.

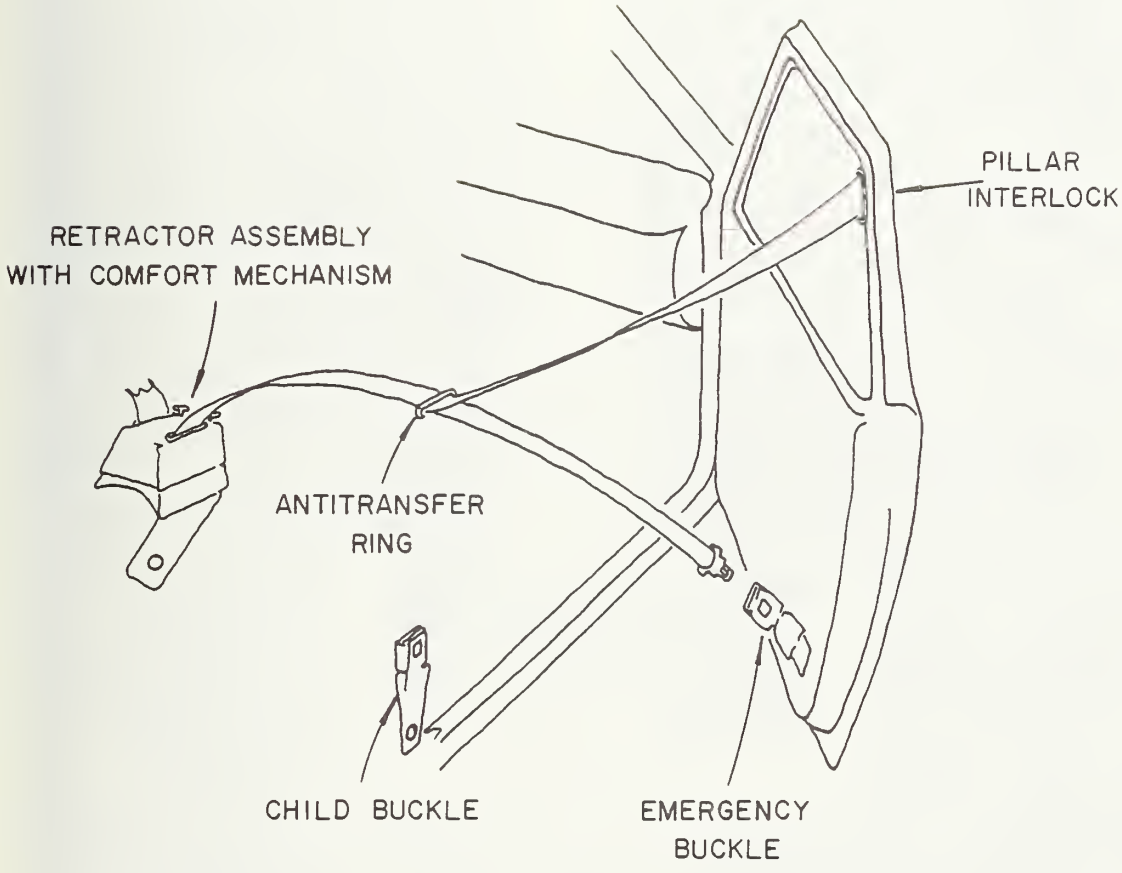

Figure 4.7 1980 Chevrolet Chevette
Automatic Seat Belt System
Passenger's Side

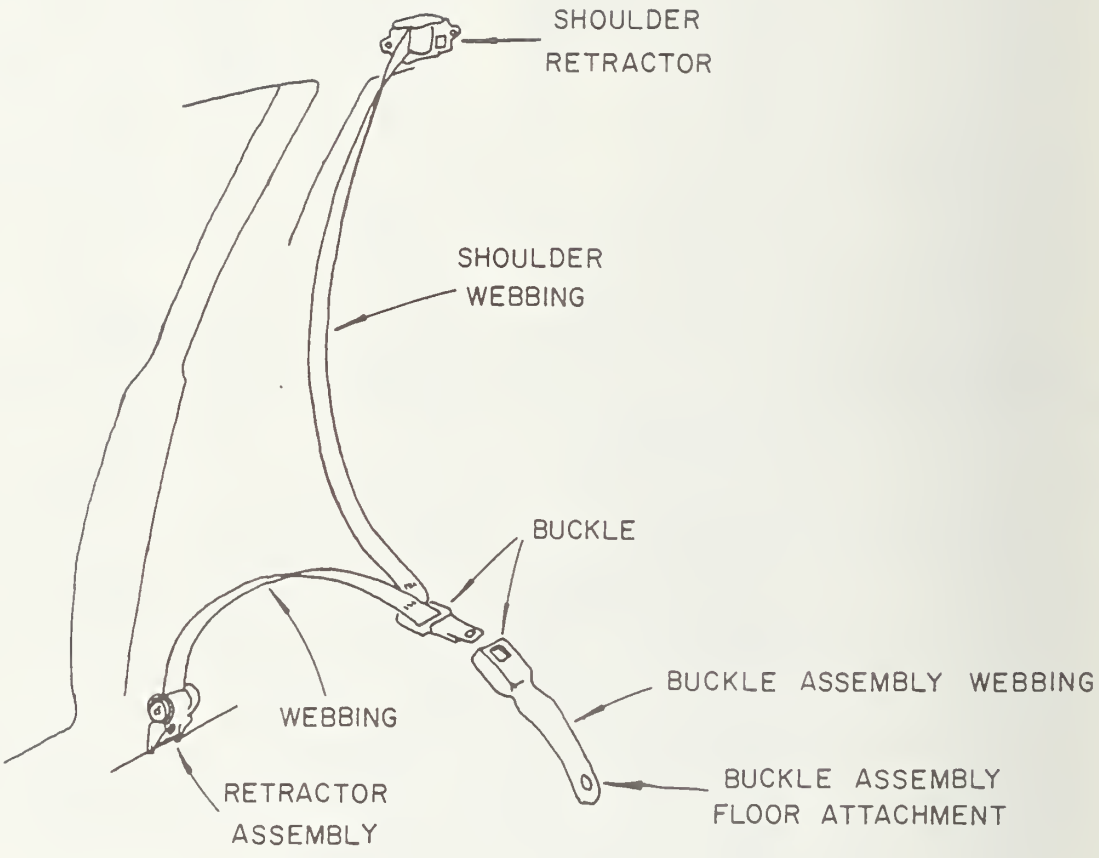

Figure 4.8 Toyota Corona
Manual Seat Belt System
1974-1978 Model Years
Passenger's Side

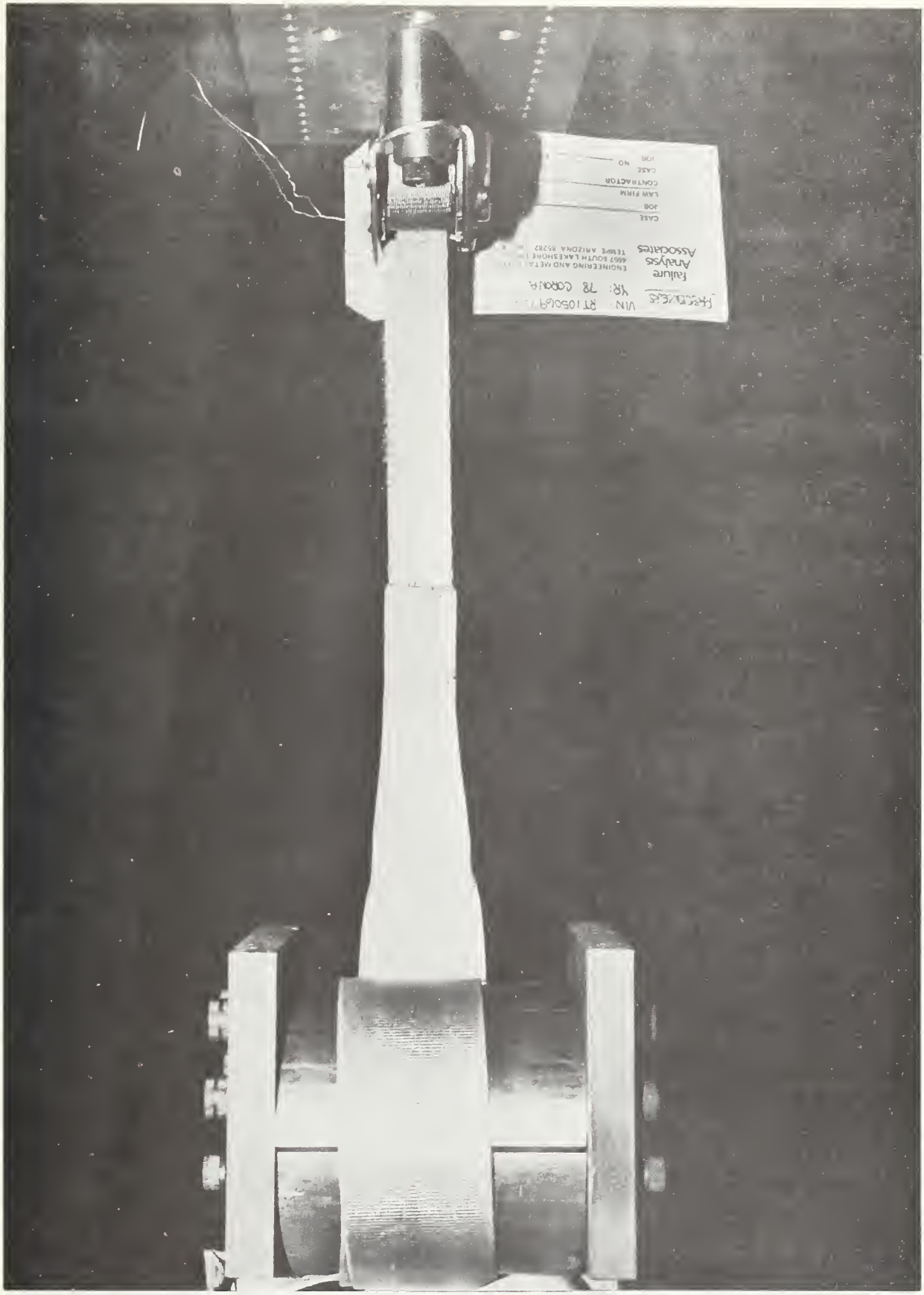

Figure 4.9 - Shoulder Retractor/Webbing Test - 1978 Corona Manual Seat Belt System.

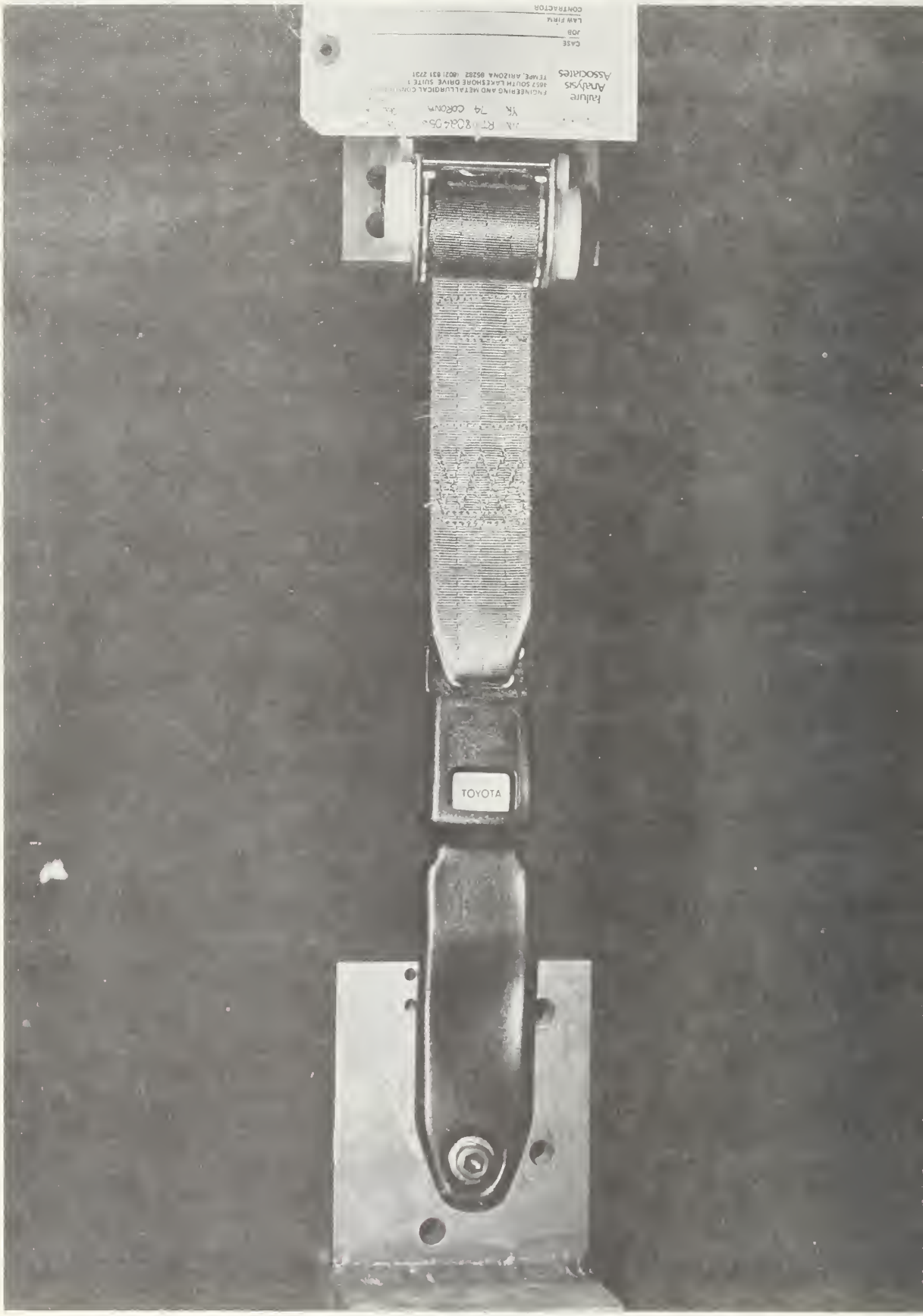

Figure 4.10 - Retractor-Webbing-Buckle Assembly Test - 1974 Corona Manual Seat Belt System.

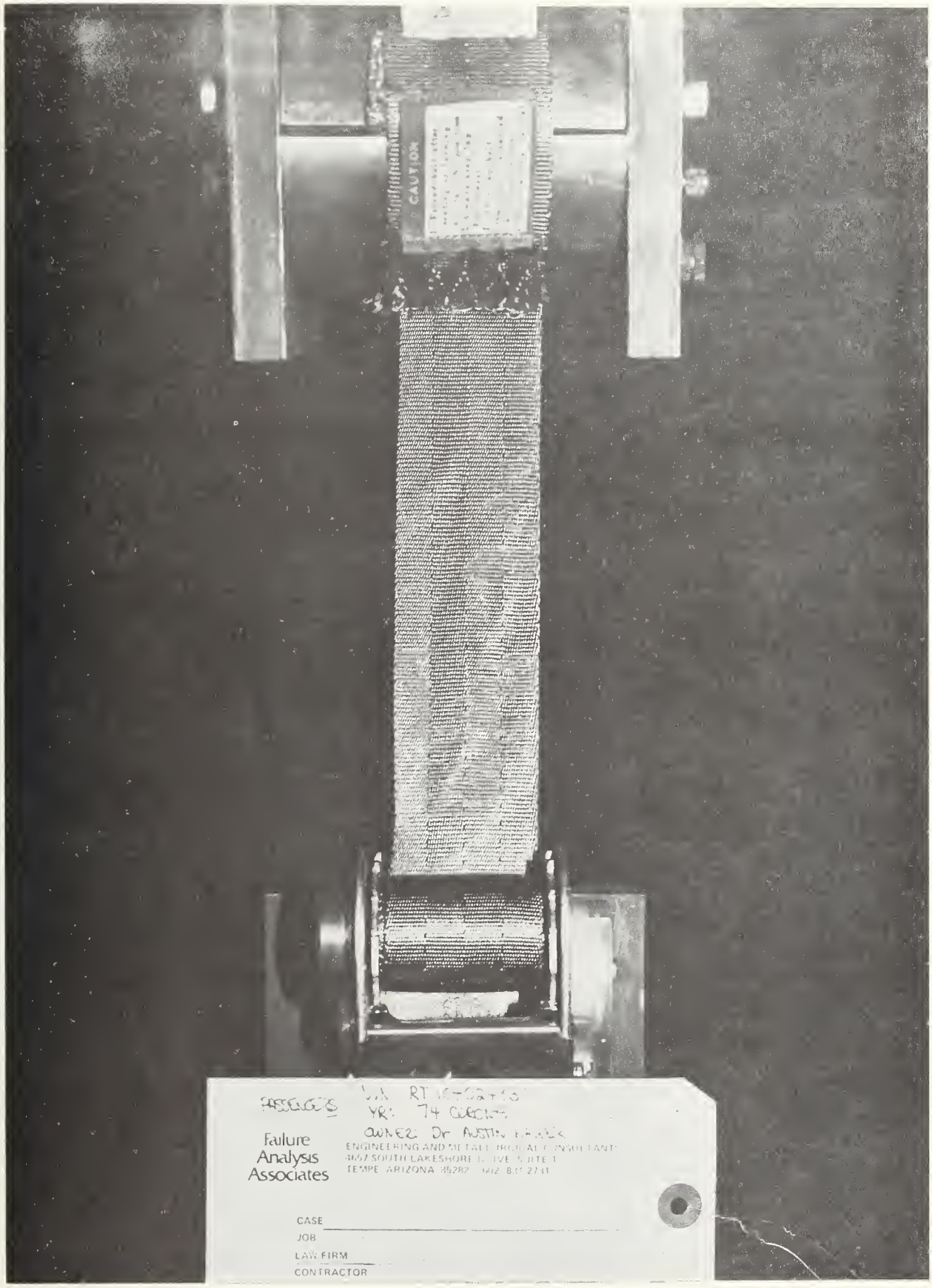

Figure 4.11 - Retractor Latch Test - 1974 Corona Manual Seat Belt System.

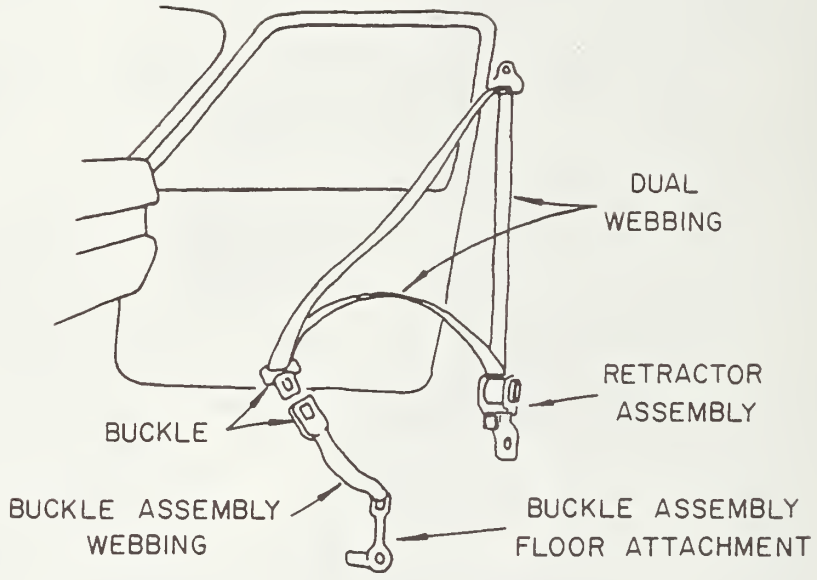

Figure 4.12 Toyota Corona
Manual Seat Belt System
1979 Model Year
Passenger's Side

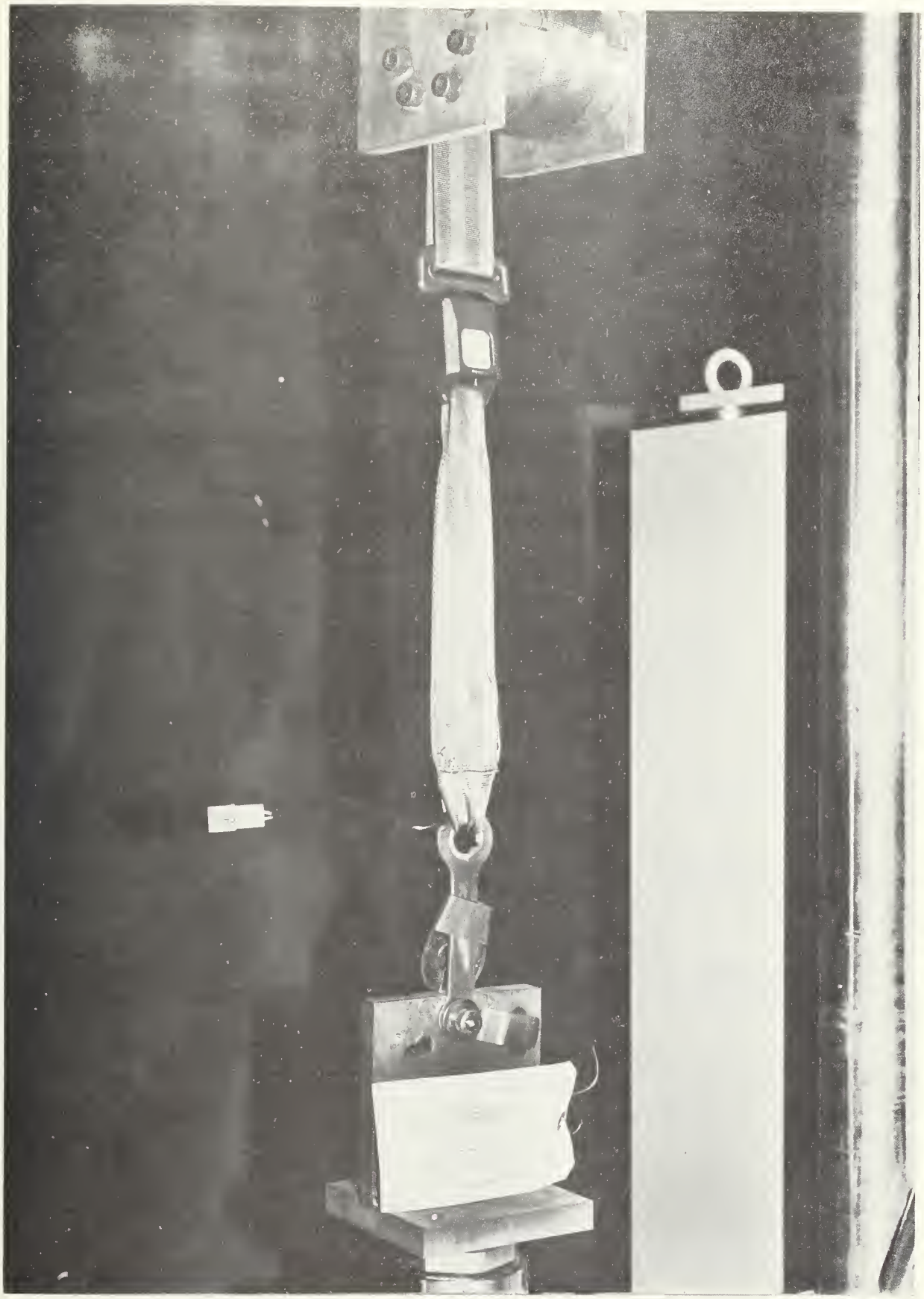

Figure 4.13 - Buckle Assembly Test - 1979 Corona Manual Seat Belt System.

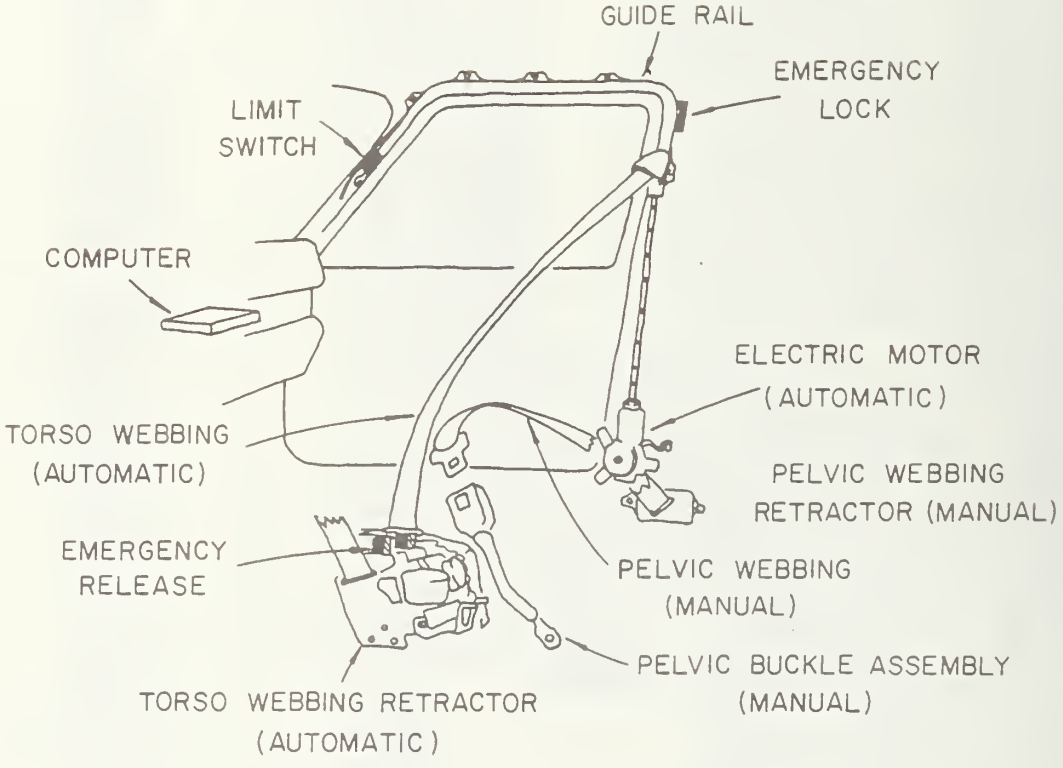

Figure 4.14 Toyota Corona
Automatic Seat Belt System
Passenger's Side

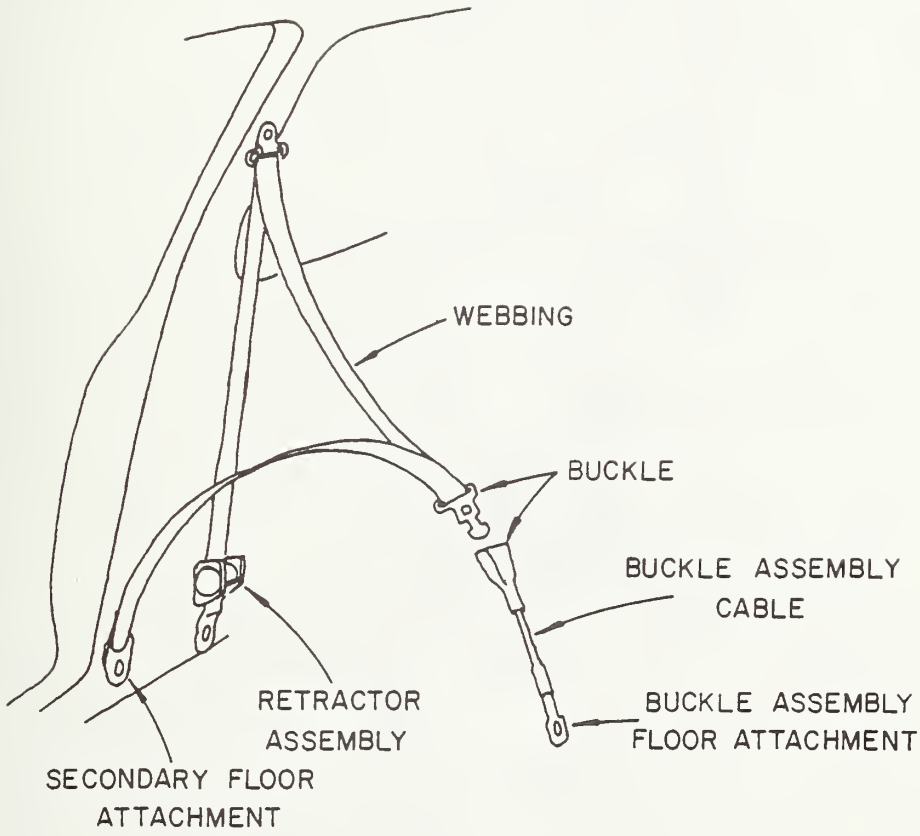

Figure 4.15 Volkswagen Rabbit
Manual Seat Belt System
Passenger's Side

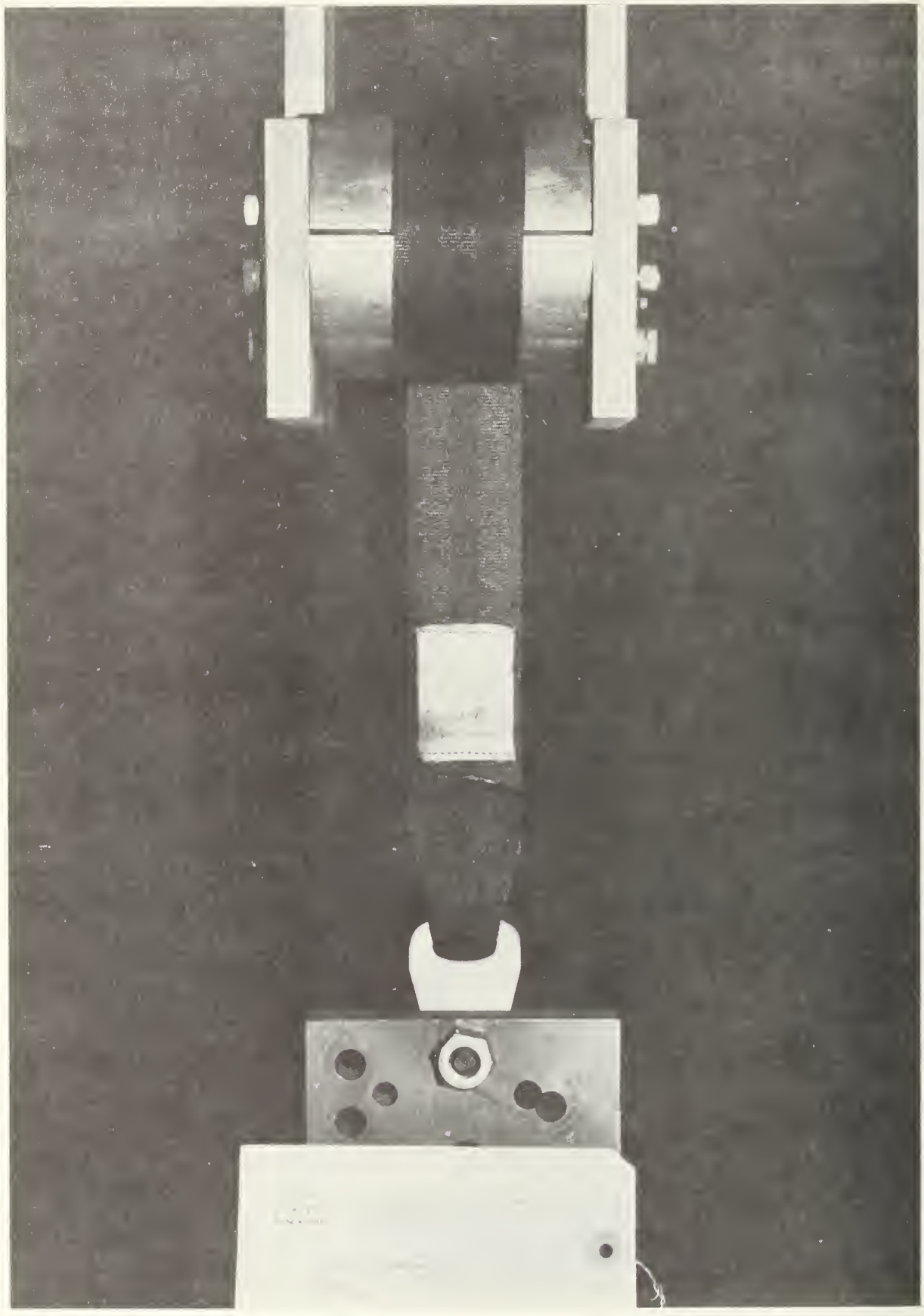

Figure 4.16 - Floor Attachment Fitting Test - 1976 Rabbit Manual Seat Belt System.

Figure 4.17 - Retractor Latch Test - 1976 Rabbit Manual Seat Belt System.

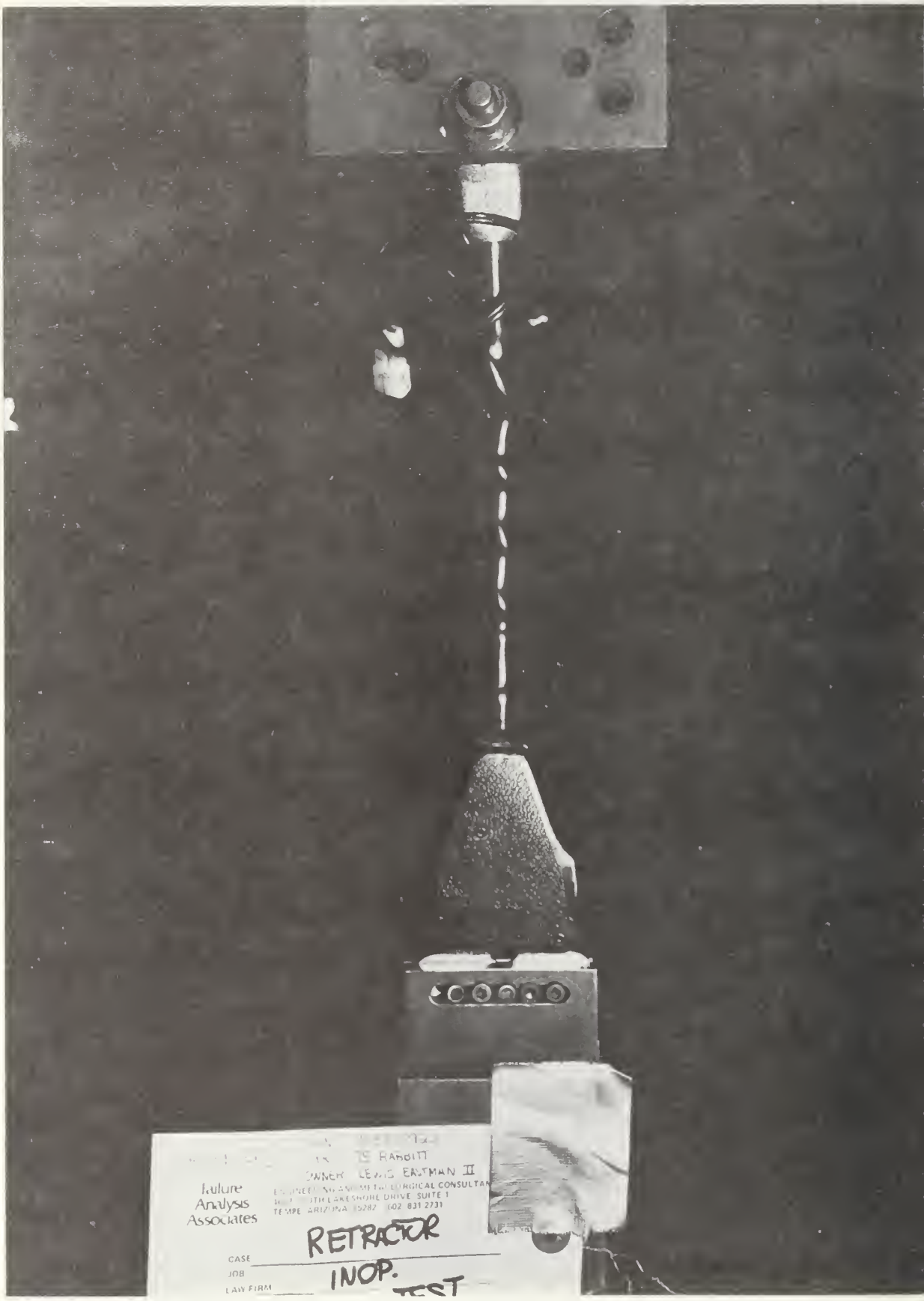

Figure 4.18 - Buckle Assembly Test - 1975 VW Rabbit Manual Seat Belt System.

Figure 4.19 - Tongue Fracture (Buckle Assembly Test) - 1975 Rabbit Manual Seat Belt System.

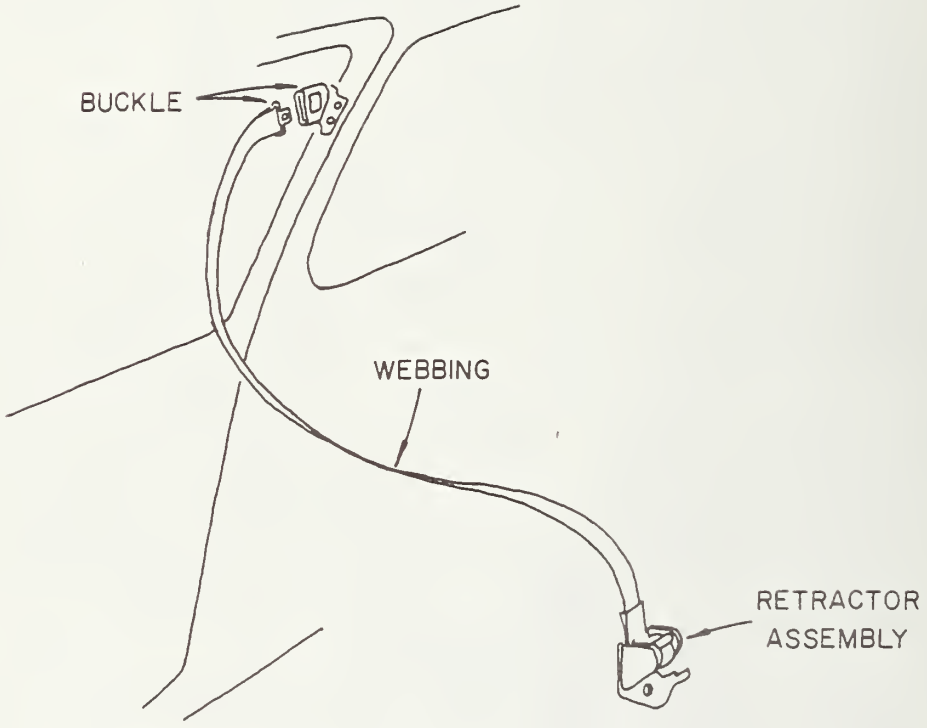

Figure 4.20 Volkswagen Rabbit
Automatic Seat Belt System
Passenger's Side

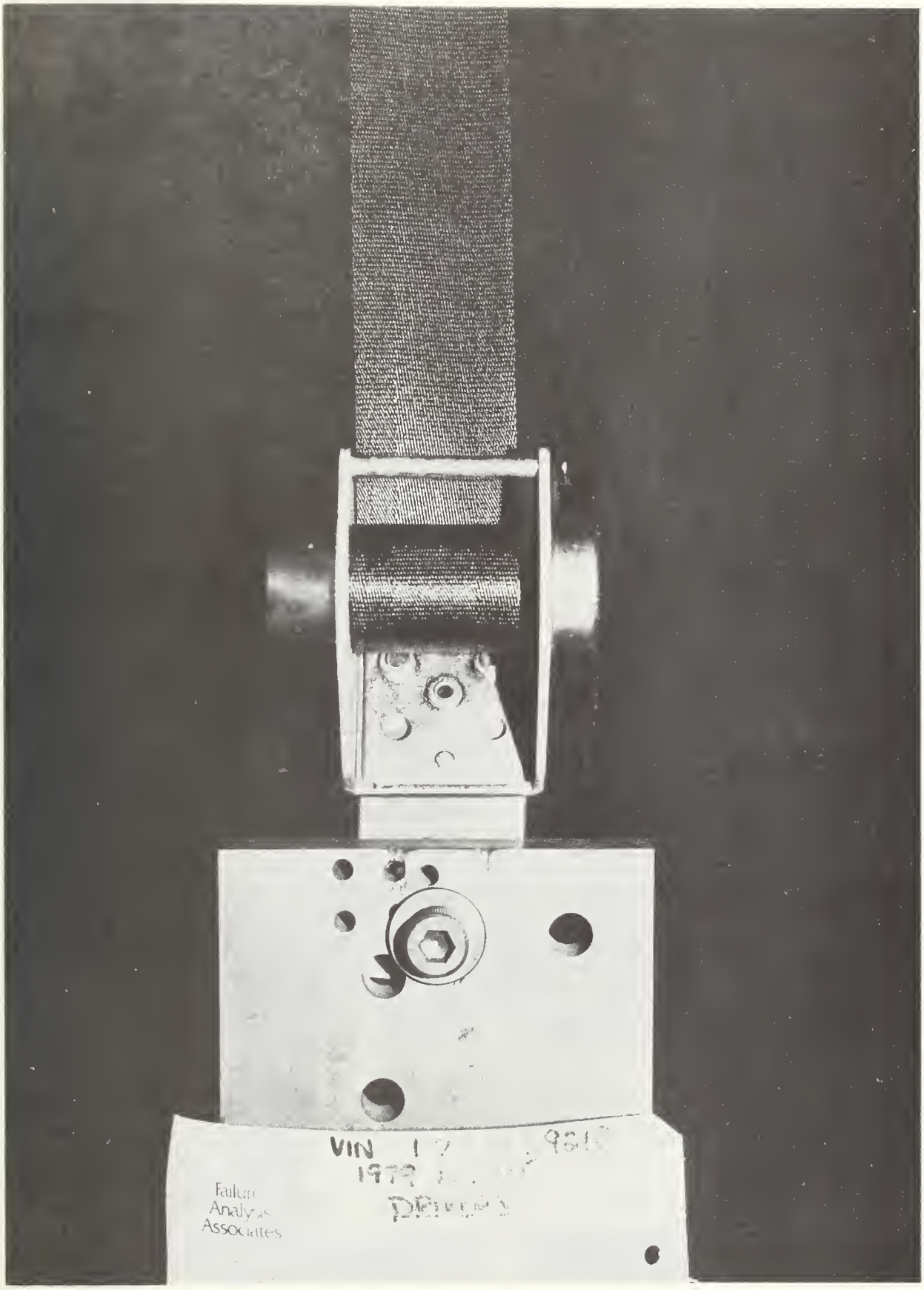

Figure 4.21 - Retractor Latch Test - 1979 VW Rabbit Automatic Seat Belt System.

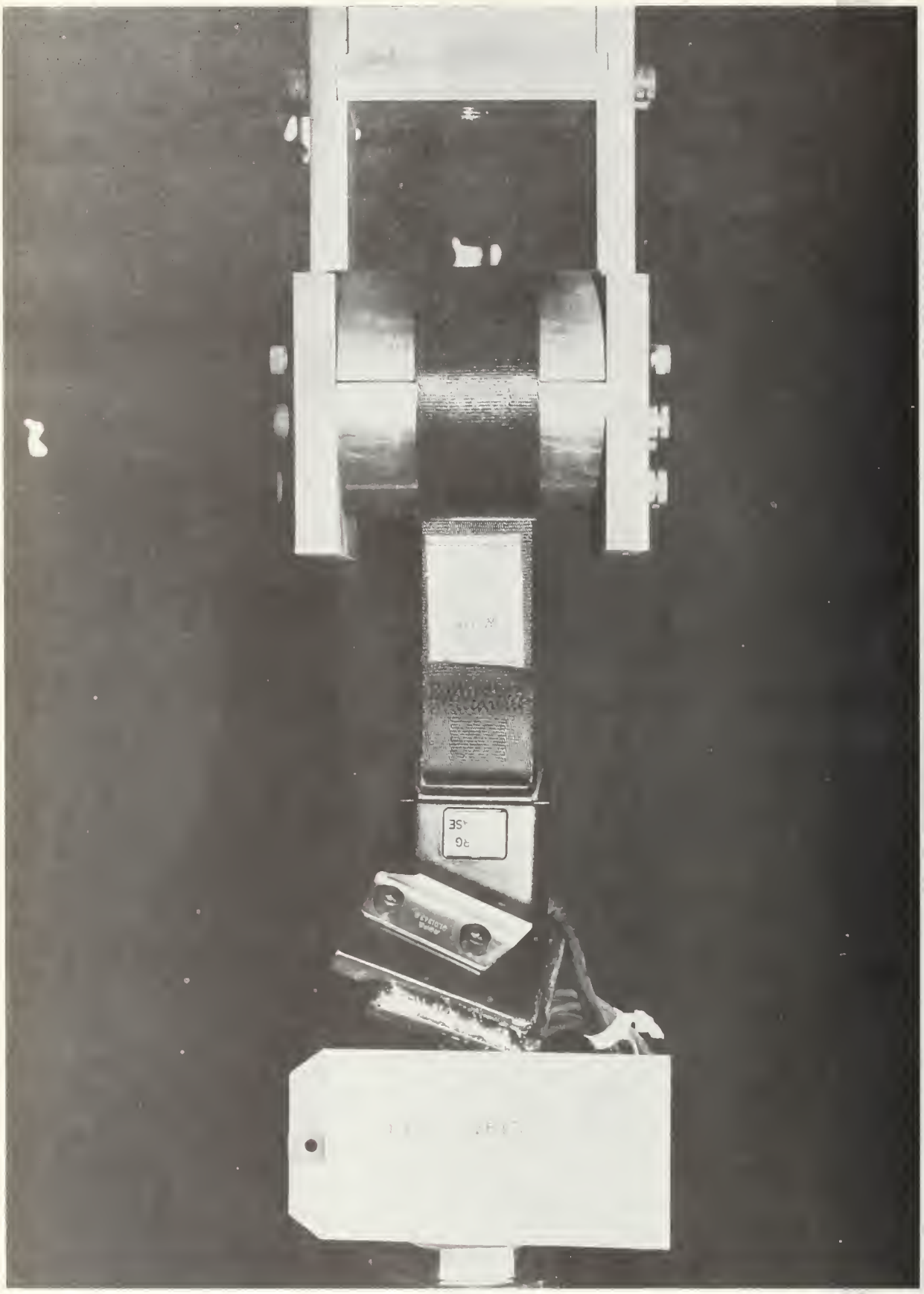

Figure 4.22 - Buckle Assembly (w/Webbing) Test - New VW Rabbit Automatic Seat Belt System.

Failure
Analysis
Associates
FAA-82-2-14

Figure 4.23 - Buckle Assembly Test (w/o Webbing) - 1975 Rabbit Automatic Seat Belt System.

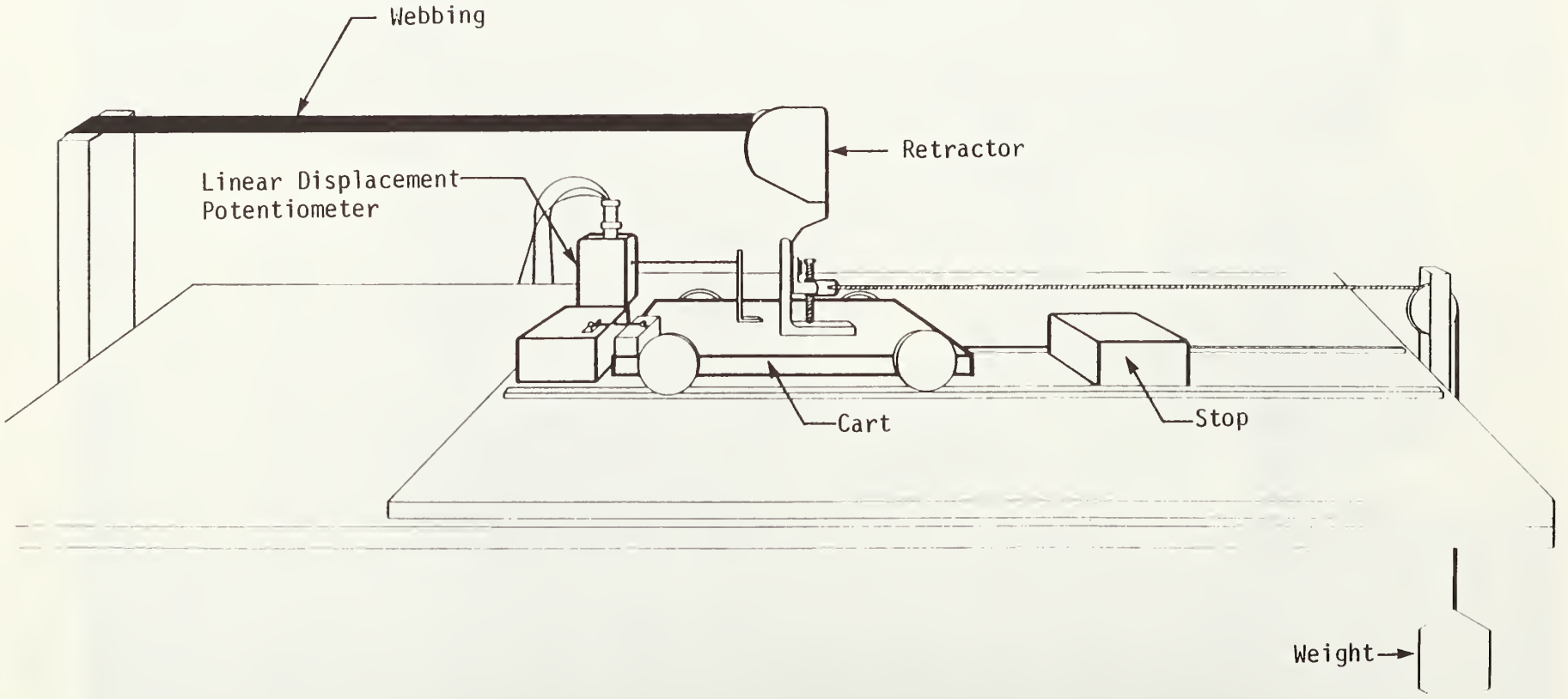

Figure 4.24 - Retractor Acceleration/Engagement Testing Apparatus.

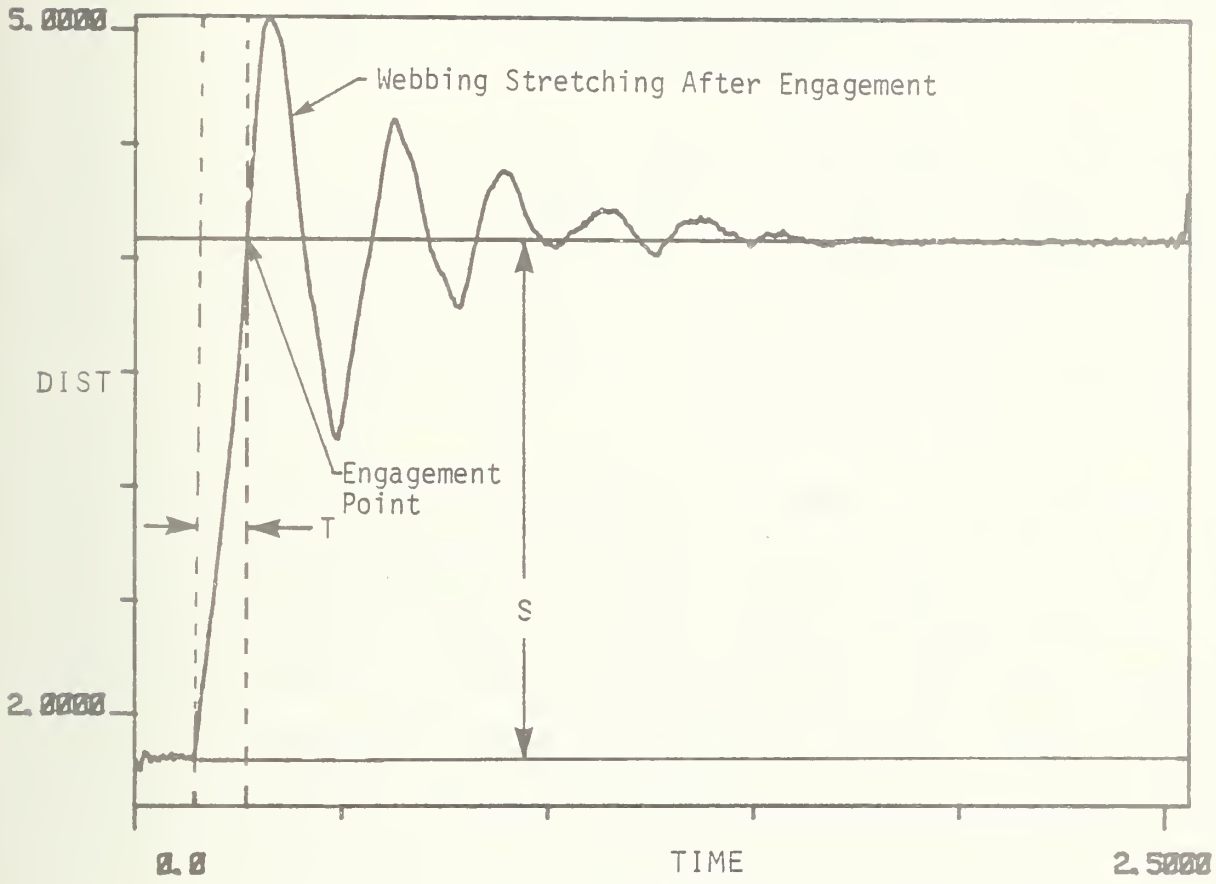

Figure 4.25 - Typical Displacement vs. Time Curve Used to Calculate Retractor Acceleration.

5.0 RELIABILITY ANALYSIS

5.1 ORGANIZATION OF ANALYSIS AND CASES CONSIDERED

In this section, the laboratory retractor displacement and seat belt component strength data are evaluated for trends and seat belt reliability. The analysis appears in four parts.

In the first, the retractor displacement data (Section 4.3) is reviewed to assess the structure of retractor displacement behavior. The results are then used to compute estimates for probability of excessive displacement for the seat belts tested for each vehicle type (i.e. Toyota Corona, VW Rabbit, Chevette).

In the second, the component strength data generated using the FMVSS No. 209 testing (Section 4.2) are evaluated. Degradation due to age and use and other possible factors influencing strength are treated where sufficient failure data exists. Extraction of information from components that were loaded but not failed was made possible through the use of censored data analysis techniques developed previously by FAA under Electric Power Research Institute funding. In this way, the number of comparisons that could be treated for the number of strength tests conducted was more than double what could have been evaluated by conventional techniques alone.

In the third part of this section, the loads and strength data are combined to compute probabilities of seat belt failure due to loss of component strength. For this purpose, load data for frontal impact at 29.4 miles per hour are used for each vehicle. The strength data for the components are normalized with respect to equivalent applied

loadings. The results of the assessments of degradation trends from the second part of this section are then used to construct modeling for regression analysis. The regression analyses provide predicted strengths as a function of seat belt age and usage together with variance/covariance matrices from which prediction variances are estimated for each of the cases considered. These results are combined with the variances on loadings to compute the probability of loads exceeding seat belt system and selected subsystem strengths.

In the fourth part, an assessment of seat belt reliability in a 29.4 mph test frontal impact is attempted for the seat belts as represented by the laboratory test data. For this purpose, the reliability relationships are constructed and enabling assumptions defined first. The failure probabilities from the load-strength analysis are then combined with the retractor displacement failure probabilities to estimate seat belt reliability for each case considered.

Essentially, these cases include:

For the Toyota Corona:

1. A pre-79 manual seat belt
2. The automatic shoulder belt as represented by equivalent manual seatbelt components
3. The combined automatic shoulder and manual lap belt system as represented by equivalent manual seat belt components

For the VW Rabbit:

1. The manual seat belt
2. The automatic seat belt

3. An assumed redesigned version of the automatic seat belt by deletion of the weakest component from analysis

For the Chevette:

1. The manual seat belt whose components are used to represent the automatic seat belt
2. An assumed redesigned version of the seat belt by deletion of the weakest component from analysis

In each case, reliability is estimated for a new belt and a 5-year old belt. The fourth part of the section closes with a discussion on the limitation and significance of the results obtained.

The last part of the section provides an evaluation of the information gained from vehicle owners contacted. Essentially, this consists of determining the nonresponse rate for the target populations and that part of the population that constituted the pool for acquisition of used seat belts. In addition, the complaint rates and failure rates among seat belt users are discussed and compared among vehicle makes. A comparison of complaint rates and failure rates for manual versus automatic seat belts is also discussed for 75/76 model year and 79 model year VW Rabbits.

5.2 RETRACTOR DISPLACEMENT

The retractor acceleration-displacement tests conducted at the FAA Phoenix office for VW Rabbit, Chevette, and Toyota seat belts are described in Section 3 above. In all cases (Toyotas, VW Rabbits, and Chevettes), termination of webbing extension from the retractors by

the pendulum catch was tested and measured. The VW Rabbit seat belt retractors also have an inertial wheel catch operating with the pendulum that sometimes catches the webbing before the pendulum. All of the acceleration-displacement results, including a set of inertial wheel catch results obtained separately for contrast on Rabbit seat belts, appear in Appendix N. For analysis, these results are condensed into a single table (Table 5.1).

Discussion of the analysis follows in two steps. The first is to assess retractor displacement behavior, while the second step is to estimate probability of excessive displacement for each of the three vehicle makes considered.

For both steps, analysis requires computation of geometric mean and standard deviation of log retractor displacements for the twenty trials of each retractor tested (Table 5.2). With ten VW Rabbit retractors tested, the same statistics (geometric mean and standard deviation) are computed for all trials among the 1975/76 model year and for those among the 1979 model year groupings of Rabbit retractors. In addition, geometric mean and standard deviations are computed for all trials among the retractors of each vehicle type.

To assess retractor displacement behavior among VW Rabbit retractors, several comparisons can be made. First, a comparison of the 75/76 model year retractors with 79 model year retractors indicates no degradation of webbing retention with age is apparent within the first 5 years of usage. Second, a comparison of automatic seat belt retractors with manual seat belt retractors indicates no significant difference between the two seat belt types. This is seen by counting

three automatic seat belt geometric means above the "all" seat belts geometric mean of .7090 inches and three below and similarly the same for the 4 manual seat belt retractors (i.e. 2 above, 2 below). The differences between cities are well within a single standard deviation hence not at all significant with the data available.

To lend further insight, an analysis of variance (ANOVA) was conducted on the retractor displacement data for each vehicle. In particular, the mean square of residuals within retractor units was computed and compared with the mean square of residuals between retractor units. The mean square (also known as an estimate for variance) is the square of the standard deviation. In addition, a residual is the difference between the log displacement for an individual trial and the mean of the log displacements for the group of trials in question.

The between units mean square is obtained as follows. First, consider the VW Rabbit statistics on Table 5.2 as an example and compute the sum of squares for VW Rabbit retractor data as a whole. This is done by squaring the standard deviation and multiplying by the number of degrees of freedom. That is $(.352840)^2 \times 199 = 24.774717$ on Table 5.2

The within units sum of squares is computed by squaring the standard deviations for the data of each retractor, summing the resulting mean squares (which sums to 1.029135 for Rabbits), and multiplying by the number of degrees of freedom for each retractor. That is 1.928135 x 19 = 19.553565 on Table 5.2. The corresponding total within units degrees of freedom is 10 units x 19 degrees of freedom per unit - 190

degrees of freedom. The between units sum of squares is the difference between the total sum of squares and the total within units sum of squares. That is, for Rabbits we have 24.774717 - 19.553565 = 5.221152 and the corresponding number of degrees of freedom is 199 - 190 = 9. From these results, the within units and between units mean squares are immediately computed as

$$19.553565/190 = .1029135$$

$$5.221152/9 = .5801280$$

as shown on Table 5.2. Comparing the two variances, it is clear that there is considerably more variance in displacements between retractors than between trials on the same retractor. This is apparent whether we observe VW Rabbits, Chevettes, or Toyota Coronas.

As the second step, the probability of excessive displacement is computed on Table 5.3. For this purpose, it is assumed that a 5-inch web extension from a retractor on impact in an accident is the limit or failing displacement $\bar{x}_1$, for the seat belt retractor. It is also assumed that a person's chances in retractor displacement in an accident can be represented as a random selection of retractor and a random selection of trial with a given retractor. On this basis, the total variance on log displacement is the sum of within units variances and between units variance. That is, for Rabbits, $(.1029135 + .5801280)^{1/2} = .6830415^{1/2} = .826463$ (Table 5.2) for displacement log standard deviation, σ , listed on Table 5.3. The Z statistic is computed as $Z = \ln(\bar{x}_1/\bar{x}_2)/\sigma$ where $\bar{x}_2$ is the geometric mean displacement. (ln is the natural or naperian logarithm of a number). That is, for VW Rabbits, we have ln(5/.7090)/.826463 = 2.363 standard deviations of a normal distribution. From the

published tables for a normal disribution, 2.363 corresponds to a .009064 probability of retractor displacement failure.

It should be noted that the Toyota Corona seat belt retractors tested were the special 1979 model year dual manual seat belts which are not representative of other Toyota Corona seat belt retractor models. Consequently, for reliability analysis of Toyota Corona automatic and pre-79 manual system retractors, an average of VW Rabbit and Chevette retractor behavior is assumed as indicated on Table 5.3 in the absence of other data.

5.3 ASSESSMENT OF COMPONENT STRENGTH DATA

To compare the possible effects of aging, use, and other factors on seat belt strength and to initially assess seat belt reliability, a series of seat belt components were loaded to failure at the FAA Los Angeles laboratory. The components tested represent a breakdown of various designs of manual and automatic seat belts selected as available from the driver and passenger sides of Toyota Coronas, VW Rabbits, and Chevettes for various model years in the Los Angeles, Phoenix, Denver, and Houston areas. A description of these strength tests is the subject of Section 4 on Component Testing. The original data on the breaking strengths measured are provided in Appendix L.

For analysis, these data are condensed and presented on Table 5.4. Along with the failing loads, Table 5.4 shows the same loads in brackets where they occurred on adjacent components without failure. Information on the vehicle make and model year, the city where the vehicle is registered, the seat belt design, and whether

the seat belt is from the driver's or passenger's side are also provided on the Table. Matched pairs of seat belts for driver and passenger from the same vehicle are indicated by a bracket connecting the pair. Components of a given seat belt that were not included and loaded in test are indicated by a dash "-". Components that are not part of a given seat belt design are indicated by the term "N/A". Crossed out numbers indicate failure loads on failed components which are considered unrepresentative of component behavior had the component been in a vehicle instead of the laboratory test rig.

An assessment of degradation due to age and use is accomplished by comparing strengths of newer versus older components where enough data is available. In these comparisons, the effects of location on degradation and the limitations on control of seat belt selection must be considered before drawing conclusions. In addition, variations in material specification and lot quality at the manufacturing source has to be recognized as another factor influencing results. To corroborate the impact of usage, component strength comparisons are also made between matched pairs of driver versus passenger side seat belts. Comparisons between automatic and manual seat belt versions of the same component are made where possible to confirm assumptions on strength of equivalent components for the preliminary estimates of reliability for automatic seat belts using manual seat belt strength data.

The groupings of component strength data from Table 5.4 to be compared are listed on Table 5.5. The number of components (or pairs as appropriate) is given as a single or triple number in the column

entitled "sample size unloaded." A single number, n, signifies that all n components in the group have failing loads. A triple number gives the total number in the group as equal to the number of failed components plus the number of components not failed (i.e. censored) at the bracketed loads listed on Table 5.4. Where all components in a grouping have failing loads on Table 5.4, the sample mean is computed as

$$\bar{x} = \Sigma_{i=1}^{n} x_i / n$$

the standard deviation by

$$s = \frac{1}{n-1} [\Sigma_{i=1}^{n} x_i^2 - n\bar{x}^2]$$

and the number of degrees of freedom by

$$df = n - 1$$

on Table 5.5. However, with censored data, the iterative techniques of Appendix G as discussed in Section 3 must be used to compute the sample mean, standard deviation, and effective number of degrees of freedom. A computer program, ROUTINE.CENSOR, developed for this purpose for multi-level censored data was used for completing Table 5.5. An example of the output of this program for item 14, "VW Rabbit: All manual seat belt buckles", is shown on Table 5.6.

The groupings on Table 5.5 are paired and the resulting comparisons are listed on Table 5.7. To test the null hypothesis that the two groupings in each comparison have the same sample mean, a Student t test is used. For two groupings, the t statistic is computed by

$$t = (\bar{x}_1 - \bar{x}_2) \Big/ \sqrt{\left(\frac{1}{n_1} + \frac{1}{n_2}\right)\left(\frac{df_1 s_1^2 + df_2 s_2^2}{df_1 + df_2}\right)}$$

where

$$df = df_1 + df_2$$

while for the matched pairs

$$t = -\bar{x}\sqrt{n}/s$$

where the subscripts distinguish the two groupings compared. The resulting values of t statistic and degrees of freedom are listed on Table 5.7. Probability tables for the Student t distribution available in most statistics handbooks provide the corresponding values of probability also shown on Table 5.7. Upon reading the probabilities listed, small probabilities on Table 5.7 indicate a significant difference between the groupings paired. In these cases, a positive (negative) t statistic on Table 5.7 indicates the grouping listed on the left (right) of the pair in the table has the stronger components. However, among the matched pairs, a positive t statistic indicates the passenger seatbelts having the stronger components. Probabilities near .5 indicate no significant difference can be shown.

From the results on Table 5.7, the following can be said. Retractors and buckles appear to degrade in strength with usage. However, lot quality or material specification changes are of sufficient size to alter apparent trends. Webbing may degrade although perhaps more with age than with use. The VW Rabbit buckles for automatic seat belts appear of downgraded design strength from buckles for manual seat belts to fit the reduced expected loadings during frontal impact. However, the buckle to floor attachment in the Chevettes

appear to have the same strength between manual and automatic seat belts.

5.4 LOAD-STRENGTH ANALYSIS

Seat belt reliability depends on the resistance of the seat belts to failure under loadings during vehicle impact, that is load-strength reliability. Component failures capable of producing seat belt failure will depend on seat belt design. For example as depicted in Figure 4.8, if one of the Toyota Corona manual belt retractors failed, the other could still restrain the occupant from injury. Whereas if the Toyota Corona manual belt buckle failed, then nothing would be left to restrain the occupant. For a study of seat belt load-strength reliability using Table 5.4 with the Figures depicting the seat belt systems in Section 4.2 as a basis, nine cases have been selected (Table 5.8). Essentially, the selection is intended to support reliability estimation for the seat belts as follows:

1. Manual seat belts loaded as in the laboratory tests.
2. Automatic seat belts loaded as in the laboratory tests with components equivalent to the manual seat belts.
3. Automatic seat belts redesigned by deletion of the weakest component.

Modeling for each case is based on the insights drawn from the analysis of Table 5.7 and take the form

$$\ln y = 1\beta_1 + x\,\beta_2 + x\,\beta_3\,\delta_{side,pass} + e$$

$$\ln y = 1\beta_1 + x\,\beta_2 + e$$

where y is the observed component strength; x is the seat belt age in years as of 1981; $\delta_{side,pass}$ is the Kronecker delta equal to 1 for passenger belts and 0 otherwise; β_1, β_2, β_3 are parameters to be estimated from the data, and e is the residual or error of observation assumed to be random. The use of the natural logarithms (ln y) arises from the possible range of srengths and loads being from 0 to ∞ so that least squares estimators will more realistically fit possible data.

To conduct a load-strength analysis the component test loads of Table 5.4 must be normalized into the form of equivalent applied seat belt loadings. Loading factors, which are derived in Section 3 to be divided into the component test loads for this purpose, are listed on Table 5.9 for each component for each vehicle and seat belt design. These loading factors are divided into the component test loads of the corresponding design seat belts of Table 5.4 to obtain the normalized data for Table 5.9.

Each of the nine cases listed on Table 5.8 is represented by a corresponding page of Table 5.9. For each case, the component whose failure constitutes failure for the case is identified as critical by black bordering of the corresponding normalized load. In all cases but the first one, the critical component in a seat belt is the weakest one as demonstrated by the lowest uncensored loading. In the first case for failure of total system strength of Toyota manual belts, failure of one web and retractor would not lead to seat belt

failure until additional components failed. Consequently, the critical component is the lessor of the (1) weakest part of the strongest retractor and web or (2) the weakest of buckle, buckle web, and floor attachment. In the second case the failure of the weakest of two belts in the Toyota manual system, the buckle and floor attachment part of the system is not under analysis so that the corresponding failure and nonfailure load data columns are blanked out. That is in all cases, component columns are blanked out if the components are not part of a seat belt design or are strengthened hence deleted by redesign.

During the component testing, not all components of every seat belt could be tested. As a consequence, the critical loadings for components exposed less often than other components among the seat belts must be weighted to compensate for their consequent and proportional lack of reported failures. The weights, W_i, for analysis are calculated for each i th component of the I components in a seat belt by

$$W_i = \frac{\sum_{j=1}^{I} n_{fj}}{n_{ri}} \Big/ \sum_{k=1}^{I} \frac{n_{fk}}{n_{rk}}$$

where n_{fi} = number of seat belts in which the recorded failing test load of the i th component is the critical load constituting failure for the case.

n_{ri} = number of seat belts in which the i th component was loaded sufficiently to either cause failure for the case or eliminate the component as a possible cause.

To aid in the calculation, the values of n_{fi} (number of critical failures) and n_{ri} (number at risk) are listed near the bottom of each

component column on Table 5.9. The resulting weights are listed at the bottom of each component column on Table 5.9.

With the critical failure loads data prepared for analysis on Table 5.9 and the modeling on Table 5.8, a computerized regression analysis was performed to compute least squares estimates for the parameters, $\beta_1, \beta_2, \beta_3$ of the modeling in each case. An example output of this least squares analysis appears as Table 5.10. The analysis output includes the variance/covariance matrix listed as the mean square for the model fit to data and the inverse of the product matrix (also known as the inverse of the information matrix). The results of the analysis are used in the modeling to predict geometric mean values of seat belt strength for the circumstances of each seat belt that was laboratory tested. These values are listed along side the observed critical failure loads and the difference (i.e. residuals) between observed and predicted values. The weights assigned to each observation are listed with the corresponding seat belts.

For some of the cases, analysis and the assessments from Table 5.7 indicate lot variations as possibly so significant that pooling of data without attempting to model trends is recommended with the available data. This was done for cases 4 - the Toyota automatic shoulder belt, and 7 - the Rabbit automatic seat belt redesigned as assumed for comparisons. In the case of the Toyota automatic shoulder belt, one load is censored so that the iterative censored data analysis program, ROUTINE.CENSOR, was necessary to find a geometric mean, variance, and effective degrees of freedom. The output is given as Table 5.11.

The loads data from frontal impact tests at 29.4 mph discussed in Section 3 are listed on Table 5.12. For analysis, the geometric averages $\bar{x} = \exp\left(\frac{1}{n}\Sigma_{i=1}^{n} \ln x_i\right)$ and the variances on the logarithms of loadings $s^2 = \frac{1}{n-1}\left[\Sigma_{i=1}^{n} (\ln x_i)^2 - n (\ln \bar{x})^2\right]$ are computed and listed on the Table.

The load-strength analysis is completed in two additional steps. The first (Table 5.13) is to compute the load-strength standard deviations from the results of Tables 5.10, 5.1, 5.12. the second (Table 5.14) is to combine the geometric mean strengths and geometric mean loads with the standard deviations to compute the load-strength failure probability for each of the nine cases of Table 5.8. In each case, the reliability analysis is done for new and for 5-year old seat belts on the driver's side.

For the first step, the projected variance on predicted strength is computed on Table 5.13 using

$$\sigma_1^2 = \Sigma_{i=1}^{2} \frac{d \ln y}{d\beta_i} \Sigma_{j=1}^{2} \frac{d \ln y}{d\beta_j} \sigma_{ij}^2$$

The model gradients, $\frac{d \ln y}{d\beta_i}$ for i = 1,2, on Table 5.13 are computed from the models listed on Table 5.8 using x = o for new seat belts and x = 5 for the 5-year old 1976 belts. Note that for the driver's side seat belts $\delta_{side,pass} = 0$ so that $\frac{d \ln y}{d\beta_3} = 0$ hence only the first terms σ_{11}^2, σ_{12}^2, σ_{21}^2, σ_{22}^2 of the variance/covariance matrix need appear in the analysis. The covariances σ_{ij}^2 are listed on Table 5.13 as the product of the MEAN SQUARE and the inverse of the product matrix elements listed on Table 5.10. The pooled data variance on predicted strength σ_1^2 is the square of the standard deviation listed on Table 5.11 for case 4 - Toyota automatic shoulder

belt. The pooled data variance for case 7 - Rabbit redesigned automatic belts is computed by the usual formula

$$\sigma_1^2 = \frac{1}{n-1}\left[\Sigma_{i=1}^{n} (\ln y_i)^2 - n (\ln \bar{y})^2\right]$$

where $$\bar{y} = \exp\left(\frac{1}{n} \Sigma_{i=1}^{n} \ln y_i\right)$$

from the Table 5.9-7 strength data. The variances σ_2^2 on seat belt loads from 19.4 mph frontal impact are transcribed from Table 5.12. The load-strength standard deviation σ follows immediately as $[\sigma_1^2 + \sigma_2^2]^{1/2}$ on Table 5.13.

To complete the load-strength analysis, the load-strength standard deviation, σ , (Table 5.13), the geometric mean strengths, $\bar{x}_1$, (Tables 5.10 and 5.11), and the geometric mean load, $\bar{x}_2$, (Table 5.12) are transcribed to Table 5.14. The geometric mean for the pooled Table 5.9 - 7 strength data is computed by $\bar{y} = \exp\left(\frac{1}{n} \Sigma_{i=1}^{n} \ln y_i\right)$ for the case 7 - Rabbit redesigned automatic belt (combined seat belt ages). With the assumption of log normally distributed strength and loads, the Z statistic is computed as

$$z = \ln \frac{\bar{x}_1}{\bar{x}_2} / \sigma$$

for Table 5.14. Tables of the normal distribution available in most statistics introductory texts and handbooks provide the failure probabilities for Table 5.14 corresponding to the statistics for each case studied.

5.5 ASSEMBLY OF SEAT BELT RELIABILITY

With the loads, strengths, and retractor displacement represented by the data available to this project, an estimate of seat belt reliability is attempted here. In particular, the probabilities of excessive retractor webbing extension (Table 5.3) and of loads exceeding seat belt strength (Table 5.14) are used on Table 5.15 to estimate reliability against failure so defined. However, the significance of these estimates are limited by the sources of the data employed and the assumptions necessary to construct the estimates.

Vehicle selection for contracted reasons was not part of a formal statistically planned field survey. Within the budgetary constraints, no systematic procedure could be applied to assure that the sample selected would be a representative cross section of seat belts among Toyota Coronas, VW Rabbits, and Chevettes in the United States. In particular, the strength and displacement data are taken from vehicles in which the owners without renumeration for their time were willing to present their vehicles for seat belt replacement. Any information given by vehicle owners was that volunteered by vehicle owners without the controls associated with formal survey conditions. As a consequence, the population of inference is largely limited to the seat belts tested.

The assumptions for estimation are as follows:

1. The published loads produced experimentally by frontal impact at 29.4 mph (Table 5.12) represent accident

loadings as if experienced by seat belts in service use.

2. Friction and occupant geometry can be ignored in computing ratios of applied loads to test loads on components.

3. Five inches of retractor displacement under the conditions of the laboratory acceleration-displacement testing can define displacement failure.

4. Occupant movement and deformation, belt deformation, and vehicle interior geometry can be ignored.

5. The displacement behavior of Chevette automatic seat belt retractors is the same as for manual seat belt retractors tested at the FAA Phoenix Laboratory.

6. The displacement behavior of Toyota Corona manual and automatic seat belt retractors is an average of Rabbit and Chevette retractors tested at the FAA Phoenix laboratory.

7. For analysis here, redesign of a component is assumed to eliminate the possibility of its failure.

8. Automatic seat belt components are assumed to have exactly equivalent reliability as their manual seat belt counterparts that were laboratory tested.

9. The Toyota Corona automatic shoulder belt attachment to the electric motor and associated mountings are assumed to be immune to failure.

10. The Chevette automatic seat belt shoulder web and attachments are assumed not to impact on the seat belt reliability.

11. The loads and displacements are lognormally distributed.

12. Displacement and load-strength failures are independent events.

13. Seat belt system reliability is a function only of retractor displacement and load-strength probabilities of failure.

The relationships necessary to compute seat belt reliability are essentially as follows. For the Toyota Corona automatic shoulder belt and for VW Rabbit and Chevette seat belts (Figures 4.3,4.14,4.15, and 4.20) system reliability is the probability

$$R = (1 - P_{\text{load-strength failure}}) (1 - P_{\text{displacement failure}})$$

In the case of Toyota Corona manual seat belts (Figure 4.8), failure may occur in three alternative ways

1. The entire seat belt system suffers load-strength failure (case 1, Table 5.14).

2. Both retractors suffer displacement failure together.

3. The weakest retractor and web suffer load-strength failure (case 2, Table 5.14), and the other suffers a displacement failure.

In the case of the Toyota Corona automatic seat belt with lap belt secure (Figure 4.14), 4 modes of failure may alternatively occur

1. The shoulder belt suffers displacement failure and the lap belt suffers a load-strength failure.
2. The shoulder belt suffers a load-strength failure and the lap belt suffers a displacement failure.
3. Both belts suffer load-strength failures.
4. Both belts suffer displacement failures.

These relationships are more explicitly formulated on Table 5.15 with the load-strength probabilities, P_{sij}, for each i th case of Table 5.14 and displacement probabilities P_d from Table 5.3. The formulae are then used to compute the seat belt reliability estimates shown on Table 5.15.

From the results on Table 5.15 it is clear that the reliabilities for Toyota automatic shoulder belts, Rabbit seat belts, and Chevette seat belts are dominated by retractor displacement as a failure mode. In the case of Toyota automatic seat belts, inclusion of a secured lap belt significantly increases seat belt system reliability. It should be noted, however, that a sparsity of data has produced erratic estimates of variance that prevent assessment of trends on degradation of reliability with age and use. Moreover, this same sparsity of data and the consequent assumptions necessary for analysis have inhibited any realistic comparison of seat belt reliability between manufacturers.

5.6 INFORMATION GAINED FROM HARDWARE IDENTIFICATION PROGRAM

As pointed out in the discussion on Assembly of Seat Belt Reliability, the seat belt sample obtained for component strength and retractor displacement testing represents a special group within the vehicle population. To lend some insight into how well the seat belts selected represent the population of seat belts in use, the proportions among the results from the hardware identification program are discussed herein.

To obtain seat belts, four metropolitan areas, Los Angeles, Phoenix, Denver, and Houston were selected. These selections were made for convenience to Failure Analysis Associates offices and to assure some extremes of climate in the sample. Among the Toyota, Rabbit, and Chevette model year vehicles targeted, R.L. Polk and Company identified some 2413, 706, 889, 1797 vehicle owners in the Los Angeles, Phoenix, Denver, and Houston metropolitan areas, respectively (Table 5.16). In the attempt to contact the vehicle owners, Table 5.17 indicates that of the contacts attempted, 73% either could not be found in the phone book, would not answer their phone, or had sold their vehicle. Among the metropolitan areas this nonresponse varied from 61 to 83%.

To ascertain vehicles having seat belts in use to qualify as candidate hardware for acquisition, respondents were asked whether they often used their seat belts. Of those asked, an average of 19% said they did not use their seat belt often. This response varied from 15 to 24% among the four metropolitan areas. It also appeared that the proportion of respondents claiming to use their seat belts

often was higher for the Rabbit owners (87%) than for the Toyota or Chevette owners (79%) contacted in this program.

In the course of the Hardware Identification Program, only two (2) of the some 200 owners having no complaints about their seat belts could be persuaded to exchange their seat belts. Thus, the effective pool for seat belt selection are those respondents who would use their seat belts often and who had complaints restricting the usefulness of their seat belts. These complaints could be classified as either readiness problems or reliability problems. In the sense used here, a readiness problem means that the belt is excessively difficult or uncomfortable to use. A reliability problem means the seat belt has essentially failed or is not capable of restraining the occupant if use of the seat belt is attempted. Table 5.17 indicates that an average of 5% (3 to 10% among the four areas) of the seat belt users had seat belts with reliability problems.

Chevettes appeared to have an average failure rate of 8% (4 to 26% among the four areas) of seat belt users which seems higher than for Coronas and Rabbits, but not conclusively. The average percentage of users having any complaints is 34% (25 to 48% among the four areas). Again, Table 5.17 indicates an average ranking of vehicle types but with inconclusive results due to the variations between metropolitan areas.

For comparison of the complaint rates and failure rates of automatic versus manual seat belts, only the population of VW Rabbits contained sufficient numbers of both manual and automatic seat belts over the range of model years studied. To compensate for a possible disparity

in ages of manual and automatic seat belts, separate counts are provided the 75/76 model years and the 79 model year belts (Table 5.18). In addition, the percentages of nonuse among all respondents and percentages of complaints and failures among users are given as an average with the minimum/maximum percentages shown underneath from among the 4 metropolitan areas studied.

From these percentages on Table 5.18, it appears that the automatic belts generate fewer complaints and fewer failures than manual belts on VW Rabbits. Age does not seem to be a factor to change this conclusion. However, possible changes in quality control can not be ruled out. In the case of VW Rabbits, the most likely explanation is that with fewer components than for manual belts, automatic seat belts have less to malfunction hence fewer complaints and failures. As expected, Table 5.18 indicates a drop in nonuse of seat belts from 17% to 6% on average among respondents having automatic seat belts compared to those with manual seat belts.

In the case of the Toyota Coronas, the automatic shoulder belt has the added complexity of the electric motor, linkage, and guide rail system to contribute exposure to malfunctions. As noted from Section 3.2, the expected reliability of the electric motor itself should contribute on the order of only one to three breakdowns in 5 years among 1000 vehicles and hence not contribute to a readiness problem rate of 20 to 40% in a 5 year period. Nevertheless, the linkages, guide rail systems, and attachments to the webbing when added to the electric motor do add enough exposure to malfunction to expect the same order or readiness complaints in automatic belts as in the manual

belts in the Toyota Coronas considered here. While adding additional exposure to malfunction as a source of owner complaint, the lap belt in the Toyota Corona does provide a back up system for use when the shoulder belt is out of service awaiting repair.

If the 434 seat belt users with complaints are counted against 5805 vehicle owners identified by R.L. Polk and Company for the four areas, then the pool for seat belt selection is only 7% (5 to 14%) of the target population. Of these 434 vehicles, only 26 were brought in for acquisition of 41 used seat belt systems for retractor displacement and component strength testing. No more than 2 of the 858 respondents having no complaints could be persuaded to bring in their seatbelts for the total of 28 vehicles providing 43 used seat belt systems subjected to strength and retractor displacement testing.

TABLE 5.1

Retractor Acceleration-Displacement Tests

Vehicle	VW Rabbit									
model year	75	75	75	76	79	79	79	79	79	NEW
city	Denver	Houston automatic	Houston automatic	Los Angeles	Los Angeles automatic	Los Angeles automatic	Denver	Houston automatic	Houston automatic	—
test ID	36	38	39	43	49	50	46	47	48	51
trial # 1	.5625	1.6250	.7500	.4375	.3125	.6250	1.1250	.6250	.7500	.7500
2	1.0000	.6250	1.0000	.7500	.5625	1.0000	1.2500	.5000	.5000	1.4375
3	.6250	.6250	.6875	.4375	1.0000	.6250	.6875	.5000	.5000	.6875
4	.4375	.6250	.6875	.5625	.5625	.6250	.8125	.5000	.5000	.4375
5	.8125	.6250	.7500	.5000	.5625	.6875	1.4375	.9375	.5000	.4375
6	.8125	.6875	.7500	.5000	2.8125	.6250	.8125	1.3750	.5625	.6250
7	.8750	.6875	.7500	.4375	.5625	.7500	.7500	1.3750	.5000	.5625
8	.5625	.6250	.7500	.5000	2.0000	.3125	.5000	.9375	.5625	.6250
9	.8750	.6875	.6250	.5625	.6875	.6250	.5000	.5000	.5000	1.7500
10	.8750	.6875	.6875	.5625	.7500	.6875	.5000	2.2500	.5625	.5625
11	1.0000	.6250	.7500	.5000	.7500	.6875	.8125	.9375	.5000	.4375
12	1.0000	.6875	.7500	.8125	.7500	.6250	.9375	.9375	.5625	.3125
13	1.0000	.6875	.7500	.9375	.7500	.8125	.9375	.9375	.5000	.6875
14	1.5000	.6250	.7500	.8750	.3750	1.1250	1.0625	.5000	.5000	.6250
15	.9375	.8125	.6250	.5000	.7500	.7500	1.0625	.9375	.5000	.6250
16	1.5000	.6875	.7500	.5625	.7500	.3125	1.0625	.6875	.5625	.6250
17	1.0000	.7500	.7500	.4375	.7500	.7500	1.1250	2.7500	.5000	.8750
18	1.0000	.7500	.7500	.5625	.7500	.8125	1.1250	.9375	.5000	.7500
19	.6250	.7500	.7500	.8750	.5625	.8125	.7500	.9375	.5000	.5625
20	.6250	.8125	.7500	.6875	.6875	.6250	.7500	.9375	.5000	.6250

Vehicle	Chevette				Toyota Corona	
model year	76	76	NEW		79	79
city	Phoenix	Denver	—		Los Angeles	Los Angeles
test ID	29	32	33		21	22
trial # 1	.5000	.6875	2.1250	All displacements of webbing	.6250	.5625
2	.5625	.8125	2.8750	from retractors before	.5625	.5625
3	.5625	.4375	1.4375	termination by pendulum or	.5625	.7500
4	.5625	.9375	1.3125	inertial wheel catch are	.5625	.7500
5	.6250	.5000	.5000	measured in inches	.5625	.7500
6	.6250	.5000	.5000		.5625	.7500
7	.6250	.5000	.5625		.5625	.7500
8	.6250	.5000	.5625		.5625	.7500
9	.6250	.5000	.2500		.5625	.7500
10	.6250	.5000	.5625		.5625	.7500
11	.6250	.5000	.5625		.6250	.8125
12	.6250	.5000	1.0000		.9375	.8125
13	.6875	.5000	.6250		.6250	.8125
14	.6875	.5000	.5625		.6250	.8125
15	.6875	.5000	1.0000		.5625	.8125
16	.6875	.9375	.5625		.6250	.8125
17	1.1875	.5000	.6250		.5625	.8125
18	.5625	.5000	.6250		.3125	.8125
19	.6250	.5000	.6250		.6250	.8125
20	.5625	.5000	.6250		.6250	.8125

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TABLE 5.2

Statistics From Retractor Acceleration-Displacement Tests

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2-23-82
NHTSA seatbelts
Job 9047

Est. Test No	Seatbelts from which Retractor component systems obtained	Sample Size n	degree of freedom df	Geometric mean (inches) $\bar{x}$	mean of log displacements $\ln \bar{x}$	Standard deviation of log displacements S	seat belt design	
36	V.W. Rabbit 75 Denver	20	19	.8413	−.1728	.314841		
38	75 Houston	20	19	.7062	−.3478	.217778	automatic	
39	75 Houston	20	19	.7374	−.3046	.093540	automatic	
43	76 Los Angeles	20	19	.5813	−.5425	.252366		
49	79 Los Angeles	20	19	.7282	−.3172	.483965	automatic	
50	79 Los Angeles	20	19	.6667	−.4054	.305854	automatic	
46	79 Denver	20	19	.8630	−.1474	.304988		within units mean squares summed over 10 units
47	79 Houston	20	19	.8855	−.1216	.480632	automatic	
48	79 Houston	20	19	.5255	−.6434	.098496	automatic	
51	NEW	20	19	.6465	−.4363	.385551		1.029135
	75/76 All	80	79	.7104	−.3419	.265438		
	79---All	100	99	.7211	−.3270	.404331		
	All	200	199	.7090	−.3439	.352840		
29	Chevette 76 Phoenix	20	19	.6336	−.4563	.170121		mean squares summed over 3 units
32	76 Denver	20	19	.5506	−.5968	.224718		
33	NEW	20	19	.7360	−.3065	.561185		.394368
	All	60	59	.6356	−.4532	.375878		
21	Toyota Corona 79 Los Angeles	20	19	.5814	−.5423	.186706		mean squares summed over 2 units
22	79 Los Angeles	20	19	.7585	−.2764	.109318		.046809
	All	40	39	.6641	−.4094	.202323		

ANOVA

	Sum of Squares $SS = \Sigma_i df_i S_i^2$	degrees of freedom $df = \Sigma_i df_i$	mean square $MS = SS/df$	Geometric Mean (inches) $\bar{x}$	standard deviation of log displacements s
VW Rabbit					
Total on data set as a whole	24.774717	199		.7090	
Total within units	19.553565	190	.1029135		
Between units	5.221152	9	.5801280		
Sum of within and between units variances to compute reliability			.6830415		.826463
Chevette					
Total on data set as a whole	8.3357720	59		.6356	
Total within units	7.4929908	57	.1314560		
Between units	.8427812	2	.4213906		
Sum of within and between units variances to compute reliability			.5528466		.743537
Toyota Corona					
Total on data set as a whole	1.5964493	39		.6641	
Total within units	.8893816	38	.0234048		
Between units	.7070677	1	.7070677		
Sum of within and between units variances to compute reliability			.7304725		.854677

TABLE 5.3

Computation of Retractor Displacement Failure Probability

C.S. Davis
2-23-82
NHTSA seatbelts
9047

Vehicle and Seatbelt designs	standard deviation of log displacements σ	failing or limit displacement $\bar{x}_1$	geometric mean displacement $\bar{x}_2$	lognormal Z statistic $Z = \ln \frac{\bar{x}_1}{\bar{x}_2} / \sigma$	Estimated probability of failure P_{di}
VW Rabbit manual and automatic seatbelts	.826463	assume 5 inches	.7090 inches	2.363	.009064
Chevette manual seatbelts	.743537	assume 5 inches	.6356 inches	2.774	.002769
Toyota Corona dual manual seatbelts	.854677	assume 5 inches	.6641 inches	2.362	.009088
Toyota Corona pre 79 manual and automatic seatbelts	Assume an average of Rabbit and Chevette behavior: .786094	5 inches	.6723 inches	2.552	.005355

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TABLE 5.4-1

Laboratory Strength Tests of
Seatbelt Systems and Subsystems

seat belt Lab test No.	vehicle model year	vehicle city	floor retractor	floor retractor to buckle webbing	buckle	buckle to floor attach webbing	buckle assembly floor attach	shoulder retractor	shoulder retractor to buckle webbing	passenger or driver's seatbelt	seat-belt Design	Identified component failure	* if acceleration displacement test run
	Toyota Corona												
1	74	Los Angeles	3750	3500	(3500)	3500	(3500)	(1950)	1950	driver	manual	webbing	
2	74	Los Angeles	4150	(4150)	—	—	—	2100	(2100)	driver	manual	retractor	
3	74	Los Angeles	3600	(3600)	—	—	—	(1900)	1900	driver	manual	retractor	
4	74	Los Angeles	(2550)	2550	—	—	—	(1650)	1650	driver	manual	retractor	
6	74	Los Angeles	4400	3150	(4250)	4250	(4250)	(1550)	1550	driver	manual	retractor	
7	74	Los Angeles	4450	(4450)	3200	3200	(3200)	1950	(1950)	pass	manual	retractor	
8	74	Los Angeles	(3400)	(3400)	3400	3400	(3400)	1800	(1800)	driver	manual	retractor	
9	74	Los Angeles	3950	3350	(3600)	3600	(3600)	2100	(2100)	driver	manual	Floor mounts	
10	74	Los Angeles	3700	3150	(3700)	3700	(3700)	(2500)	2500	pass	manual	Floor mounts	
5	74	Phoenix	4000	(4000)	(3200)	3200	(3200)	(1100)	1100	driver	manual	N/A	
11	75	Denver	3800	(3800)	—	—	—	2450	(2450)	pass	manual	N/A	
17	76	Phoenix	3350	(3350)	(4190)	4190	(4190)	2200	(2200)	driver	manual	Ret Guide Ring	
18	76	Phoenix	3600	(3600)	(3600)	(3600)	(3600)	(2500)	2500	pass	manual	Mt Guide Ring	
12	76	Denver	4050	(4050)	—	—	—	2110	(2110)	driver	manual	retractor	
13	76	Denver	4250	(4250)	—	—	—	2400	(2400)	pass	manual	retractor	
14	76	Denver	3550	(3550)	—	—	—	2500	(2500)	driver	manual	retractor	
15	76	Denver	3450	(3450)	—	—	—	2800	(2800)	driver	manual	retractor	
16	76	Denver	3700	(3700)	—	—	—	2600	(2600)	pass	manual	retractor	
19	78	Los Angeles	—	3300	(3300)	(3300)	(3300)	2300	(2300)	driver	manual	retractor	
20	78	Los Angeles	—	3700	(3700)	(3700)	(3700)	2350	(2350)	pass	manual	retractor	
21	79	Los Angeles	3600	(3600)	(3950)	(3950)	3950	N/A	N/A	driver	dual	retractor	*
22	79	Los Angeles	3400	(3400)	(3950)	(3950)	3950	N/A	N/A	pass	dual	retractor	*
23	NEW	pre 79	3100	(3100)	4100	4100	(4100)	2550	(2550)	—	manual	-none-	
24	NEW	pre 79	2900	(2900)	(4050)	4050	(4050)	2500	(2500)	—	manual	-none-	
25	NEW	pre 79	3950	(3950)	—	—	—	2300	(2300)	—	manual	-none-	
26	NEW	pre 79	3600	(3600)	(4400)	4400	(4400)	2800	(2800)	—	manual	-none-	

TABLE 5.4-2

Laboratory Strength Tests of
Seatbelt Systems and Subsystems

Seat belt Lab test No.	vehicle model year	vehicle city	Retractor	retractor to floor/buckle Webbing	Buckle	buckle to floor attach Web/Cable	buckle assembly Floor attach	second Floor attach	passenger or driver's seatbelt	Seatbelt design	Identified component failure	* if acceleration displacement test run
	VW Rabbit											
36	75	Denver	1950	3500	(5000)	5000	(5000)	(3500)	driver		retractor	*
37	75	Denver	1350	5100	5000	(5000)	(5000)	3500	passenger		retractor	
40	75	Denver	~~3350~~	3550	5950	(5950)	(5950)	(3550)	driver		retractor	
41	75	Denver	~~2450~~	3350	(5200)	5200	(5200)	(3350)	passenger		retractor	
38	75	Houston	2850	3350	4600	N/A	(3350)	N/A	driver	passive	Ret, Buckle	*
39	75	Houston	3500	3150	(3150)	N/A	(3150)	N/A	passenger	passive	Ret, Buckle	*
42	76	Los Angeles	1500	3750	—	—	—	(3750)	driver		retractor	
43	76	Los Angeles	1650	3800	—	—	—	(3800)	passenger		retractor	*
44	76	Denver	~~1800~~	3300	—	—	—	(3300)	driver		retractor	
45	77	Phoenix	~~2400~~	3300	—	—	—	(3300)	driver		Ret./Adjust Ring	
49	79	Los Angeles	3650	3650	4200	N/A	(4200)	N/A	driver	passive	retractor	*
50	79	Los Angeles	3500	3500	4550	N/A	(4550)	N/A	passenger	passive	retractor	*
46	79	Denver	~~2400~~	4600	—	—	—	(4600)	driver		retractor	*
47	79	Houston	2950	3700	3750	N/A	(3750)	N/A	driver	passive	retractor	*
48	79	Houston	3150	3550	4250	N/A	(4250)	N/A	passenger	passive	retractor	*
51	NEW		4050	3400	—	—	—	(3400)	—		—none—	
52	NEW		1800	3950	4450	(4450)	(4450)	(3950)	—		—none—	
53	NEW		2000	3600	4450	N/A	(4450)	N/A	—	passive	—none—	
									passive = automatic seatbelt design			
	Chevette											
28	76	Los Angeles	~~3150~~	2900	(3800)	(3800)	(3800)	(2900)	driver		retractor	
30	76	Los Angeles	3550	3800	(3800)	(3800)	(3800)	(3800)	driver		retractor	
27	76	Phoenix	~~3300~~	3800	(3800)	3800	(3800)	(3800)	driver		Frayed Belts	
29	76	Phoenix	3300	3300	(3300)	(3300)	(3300)	(4150)	driver		retractor	*
31	76	Denver	~~3200~~	3700	3650	(3650)	(3650)	4100	driver		retractor	
32	76	Denver	3500	3400	3100	(3100)	(3100)	(3400)	passenger		retractor	*
33	NEW		3600	4100	(3650)	3650	(3650)	(4100)	—		—none—	*
34	NEW		4850	4000	(3650)	3650	(3650)	(4000)	—		—none—	
35	NEW		—	(4000)	(4000)	4000	(4000)	N/A	—	passive	—none—	
35.5	NEW		—	(3350)	(3350)	3350	(3350)	N/A	—	passive	—none—	

Notes:
1. Loads are measured in lbs
2. Bracketed numbers are censor levels at which increasing load stopped due to failure elsewhere
3. Crossout numbers represent loads on jammed components whose strength was not tested
4. N/A indicates component not part of seatbelt design hence doesn't exist!
5. asterisks(*) are estimated seatbelt identities of acceleration/displacement tests
6. linked seatbelts represent seatbelts taken from the same vehicle

TABLE 5.5

Statistics From Laboratory Strength Data to Analyze Loss of Strength

C.S. Davis
2-10-82
NHTSA Seatbelts
Job 9047

item	$\bar{x} = \Sigma x/n \quad s = \sqrt{\frac{1}{n-1}[\Sigma x^2 - n\bar{x}^2]}$ where $n = df + 1$ = effective sample size with censored observations weighted	sample size unweighted	effective degree of freedom df	sample mean $\bar{x}$	standard deviation s
	VW Rabbit				
1	Retractor : NEW	3	2	2616.67	1245.32
2	79 Houston/Los Angeles	4	3	3312.50	319.831
3	75/76 Houston/Los Angeles	4	3	2375.00	963.068
4	75/76 All	6	5	2133.33	855.960
5	driver - passenger matched pairs	5	4	-500.00	462.331
6	Ret/Floor Web: NEW	3	2	3650.00	278.388
7	79 Houston/Los Angeles	4	3	3600.00	91.2871
8	75/76 Houston/Los Angeles	4	3	3512.50	314.576
9	75/76 All	9	8	3650.00	583.095
10	driver - passenger matched pairs	6	5	-158.333	712.332
11	Buckle : NEW	2	1	4450.00	0
12	79 Houston/Los Angeles	4	3	4187.50	330.088
13	All passive seatbelt buckles	7 = 6+1	5.000	4300.02	313.003
14	All manual seatbelt buckles	5 = 3+2	3.039	5402.66	727.108
15	driver-passenger passive pairs	3 = 2+1	1.000	-425.000	106.066
	Chevette				
16	Retractor : NEW	2	1	4225.00	883.883
17	76 All	3	2	3450.00	132.288
18	Ret/Floor Web : NEW (manual only)	2	1	4050.00	70.7107
19	76 All	6	5	3483.33	354.495
20	Buckle/Floor Web : NEW (manual only)	2	1	3650.00	0
21	NEW (passive only)	2	1	3675.00	459.619
21.5	76 All	6 = 1+5	.757	3819.96	24.1275
	Toyota Corona				
22	Floor Retractor : NEW	4	3	3387.50	476.751
23	76 Denver	5	4	3800.00	339.116
24	74 Los Angeles	9 = 7+2	6.079	4004.04	337.684
25	74/76 All	18 = 16+2	15.163	3862.75	330.825
26	driver - passenger matched pairs	5 = 4+1	3.000	-112.486	242.785
27	Ret/Buckle Web : drivers of matched pairs	6 = 2+4	2.835	3910.59	591.730
28	passengers of matched pairs	6 = 2+4	2.949	4631.06	1191.07
29	Buckle : NEW	3 = 1+2	.816	4865.98	917.744
30	74 Los Angeles	6 = 2+4	2.959	4237.09	914.113
31	74/76 All	9 = 2+7	3.603	4738.61	1170.80
32	drivers of matched pairs	4 = 1+3	1.021	7236.62	3943.30
33	passengers of matched pairs	4 = 1+3	1.022	8899.94	5845.18
34	Buckle/attach Web: NEW	3	2	4183.33	189.297
35	74 Los Angeles	6	5	3608.33	358.353
36	74/76 All	9 = 8+1	7.607	3664.97	401.030
37	drivers of matched pairs	4 = 3+1	2.212	3759.20	388.757
38	passengers of matched pairs	4 = 2+2	2.197	3741.80	435.358
39	Shoulder Retractor: NEW	4	3	2537.50	205.649
40	76 Denver	5	4	2482.00	255.186
41	74 Los Angeles	9 = 4+5	4.809	2163.87	282.697
42	74/76 All	18 = 11+7	12.105	2349.74	315.443
43	driver - passenger matched pairs	6 = 4+2	4.582	-232.242	299.660
20.5	Chevette Buckle/Floor Web: NEW (manual and passive)	4	3	3662.50	265.754

Note: passive = automatic seatbelt design

Failure Analysis Associates
FAA-82-2-14

TABLE 5.6

```
ROUTINE CENSOR ESTIMATES MEAN, STANDARD DEVIATION AND DEGREES OF FREEDOM
FOR NORMALLY DISTRIBUTED DATA WHICH IS CENSORED AT SEVERAL LEVELS
(MULTI-LEVEL TYPE 1 CENSORING)

$$$  RABBIT   BUCKLE     ALL MANUAL BELTS
NUMBER OF UNCENSORED SAMPLE VALUES    N=   3
NUMBER OF CENSOR LEVELS           LEVELS=   2
MAX NUMBER OF ITERATIONS ALLOWED  LMTRY=  40
ERROR TO SIGNAL CONVERGENCE       ERLIM=0.100D-07

UNCENSORED SAMPLE VALUES:
    0.44500000D+04    0.59500000D+04    0.50000000D+04

CENSORED DATA

GROUP    CENSOR LEVEL    NUMBER OF HIDDEN VALUES
   1    0.52000000D+04       1
   2    0.50000000D+04       1

$$$  RABBIT   BUCKLE     ALL MANUAL BELTS
CONVERTED DATA FOR WHICH TERMS TO BE COMPUTED:

UNCENSORED VALUES:
   -0.44500000D+04   -0.59500000D+04   -0.50000000D+04

CENSORED DATA

GROUP    CENSOR LEVEL    NUMBER OF HIDDEN VALUES
   1   -0.52000000D+04       1
   2   -0.50000000D+04       1

FOR UNCENSORED DATA, N=  3  AVERAGE=-.513333D+04  EMS=0.383889D+06
INITIAL: MEAN=-.512000D+04  STD DEV=0.537096D+03  FOR   2 CENSORED VALUES AT  2 LEVELS IN   5 TOTAL SAMPLES
TRY  1:  MEAN=-.526599D+04  STD DEV=0.655115D+03  ERROR=0.146D+03  EFFECTIVE NUMBER=   1.318 IN   2 CENSORED
TRY  2:  MEAN=-.534089D+04  STD DEV=0.699921D+03  ERROR=0.749D+02  EFFECTIVE NUMBER=   1.164 IN   2 CENSORED
TRY  3:  MEAN=-.537595D+04  STD DEV=0.717471D+03  ERROR=0.351D+02  EFFECTIVE NUMBER=   1.095 IN   2 CENSORED
TRY  4:  MEAN=-.539162D+04  STD DEV=0.724140D+03  ERROR=0.157D+02  EFFECTIVE NUMBER=   1.063 IN   2 CENSORED
TRY  5:  MEAN=-.539835D+04  STD DEV=0.726491D+03  ERROR=0.673D+01  EFFECTIVE NUMBER=   1.049 IN   2 CENSORED
TRY  6:  MEAN=-.540112D+04  STD DEV=0.727200D+03  ERROR=0.277D+01  EFFECTIVE NUMBER=   1.043 IN   2 CENSORED
TRY  7:  MEAN=-.540219D+04  STD DEV=0.727335D+03  ERROR=0.107D+01  EFFECTIVE NUMBER=   1.040 IN   2 CENSORED
TRY  8:  MEAN=-.540257D+04  STD DEV=0.727301D+03  ERROR=0.379D+00  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY  9:  MEAN=-.540268D+04  STD DEV=0.727238D+03  ERROR=0.113D+00  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 10:  MEAN=-.540270D+04  STD DEV=0.727187D+03  ERROR=0.514D-01  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 11:  MEAN=-.540270D+04  STD DEV=0.727152D+03  ERROR=0.342D-01  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 12:  MEAN=-.540269D+04  STD DEV=0.727132D+03  ERROR=0.205D-01  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 13:  MEAN=-.540268D+04  STD DEV=0.727120D+03  ERROR=0.115D-01  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 14:  MEAN=-.540267D+04  STD DEV=0.727114D+03  ERROR=0.621D-02  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 15:  MEAN=-.540267D+04  STD DEV=0.727111D+03  ERROR=0.347D-02  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 16:  MEAN=-.540267D+04  STD DEV=0.727109D+03  ERROR=0.195D-02  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 17:  MEAN=-.540266D+04  STD DEV=0.727109D+03  ERROR=0.105D-02  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 18:  MEAN=-.540266D+04  STD DEV=0.727108D+03  ERROR=0.541D-03  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 19:  MEAN=-.540266D+04  STD DEV=0.727108D+03  ERROR=0.272D-03  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 20:  MEAN=-.540266D+04  STD DEV=0.727108D+03  ERROR=0.133D-03  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 21:  MEAN=-.540266D+04  STD DEV=0.727108D+03  ERROR=0.635D-04  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 22:  MEAN=-.540266D+04  STD DEV=0.727108D+03  ERROR=0.295D-04  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 23:  MEAN=-.540266D+04  STD DEV=0.727108D+03  ERROR=0.134D-04  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 24:  MEAN=-.540266D+04  STD DEV=0.727108D+03  ERROR=0.587D-05  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 25:  MEAN=-.540266D+04  STD DEV=0.727108D+03  ERROR=0.248D-05  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 26:  MEAN=-.540266D+04  STD DEV=0.727108D+03  ERROR=0.100D-05  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 27:  MEAN=-.540266D+04  STD DEV=0.727108D+03  ERROR=0.380D-06  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 28:  MEAN=-.540266D+04  STD DEV=0.727108D+03  ERROR=0.130D-06  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 29:  MEAN=-.540266D+04  STD DEV=0.727108D+03  ERROR=0.356D-07  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 30:  MEAN=-.540266D+04  STD DEV=0.727108D+03  ERROR=0.220D-07  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 31:  MEAN=-.540266D+04  STD DEV=0.727108D+03  ERROR=0.141D-07  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
TRY 32:  MEAN=-.540266D+04  STD DEV=0.727108D+03  ERROR=0.828D-08  EFFECTIVE NUMBER=   1.039 IN   2 CENSORED
OUT OF   5 TOTAL SAMPLED WITH AN EFFECTIVE TOTAL=   4.039 FOR   3.039 DEGREES OF FREEDOM
```

TABLE 5.7

Analysis of Strength Data for Loss of Strength Significance

C.S. Davis
2-10-82
NHTSA seatbelts
bb 9047

Test	For 2 items $t = (\bar{x}_1 - \bar{x}_2) \Big/ \sqrt{\left(\frac{1}{n_1}+\frac{1}{n_2}\right)\left(\frac{df_1 S_1^2 + df_2 S_2^2}{df_1 + df_2}\right)}$ $df = df_1 + df_2$ while for paired observations we use $t = -\bar{x}\sqrt{n}/s$	items compared	t statistic	df degree of freedom	probability of wrongly rejecting null hypothesis	Remarks
	VW Rabbit					
	Retractor					
1	NEW versus 79-Houston/LA	① - ②	-1.103	5	.20*	
2	79 Houston/LA versus 75/76 Houston/LA	② - ③	1.848	6	.06	
3	NEW versus 75/76 All	① - ④	.695	7	.30	
4	driver-passenger matched pairs	⑤	2.418	4	.04	
	Ret/Floor Web					
5	NEW versus 79-Houston/LA	⑥ - ⑦	.345	5	.4	
6	79 Houston/LA versus 75/76 Houston/LA	⑦ - ⑧	.534	6	.35	
7	NEW versus 75/76 All	⑥ - ⑨	0	10	.5	
8	driver-passenger matched pairs	⑩	.544	5	.35	
	Buckle					
9	NEW versus 79-Houston/LA	⑪ - ⑫	1.060	4	.20	
10	manual versus passive **	⑭ - ⑬	3.355	8.039	.005	
11	driver-passenger passive pairs	⑮	5.467	1.000	.06	
	Chevette (manual)					
	Retractor					
12	NEW versus 76-All	⑯ - ⑰	1.628	3	.11	
	Ret/Floor Web					
13	NEW versus 76-All	⑱ - ⑲	2.136	6	.04	
	Buckle/Floor Web					
14	NEW (manual) versus NEW (passive)	⑳ - ㉑	-.077	2	.5	
→ 14.5	Toyota Corona NEW versus 76-All	⑳.⑤ - ㉑.⑤	-.732	3.757	.3*	data inadequate
	Floor Retractor					
15	NEW versus 76-Denver	㉒ - ㉓	-1.523	7	.09*	
16	NEW versus 74-Los Angeles	㉒ - ㉔	-2.533	9.079	.02*	
17	NEW versus 74/76 All	㉒ - ㉕	-2.370	18.163	.02*	
18	driver-passenger matched pairs	㉖	.927	3.000	.25	
	Ret/Buckle Web					
19	drivers versus passengers matched pairs	㉗ - ㉘	1.062	5.784	.2	
	Buckle					
→ 20	NEW versus 74-Los Angeles	㉙ - ㉚	.767	3.775	.25	data inadaquate
→ 21	NEW versus 74/76 All	㉙ - ㉛	.129	4.419	.45	
→ 22	drivers versus passengers matched pairs	㉜ - ㉝	.335	2.043	.4	
	Buckle/attach Web					
23	NEW versus 74-Los Angeles	㉞ - ㉟	2.547	7	.02	
24	NEW versus 74/76 All	㉞ - ㊱	2.106	9.607	.04	
25	drivers versus passengers matched pairs	㊲ - ㊳	-.053	4.409	.5	
	Shoulder Retractor					
26	NEW versus 76-Denver	㊴ - ㊵	.352	7	.4	
27	NEW versus 74-Los Angeles	㊴ - ㊶	2.248	7.809	.03	
28	NEW versus 74/76 All	㊴ - ㊷	1.107	15.105	.15	
29	driver-passenger matched pairs	㊸	1.831	4.582	.07	

Notes: * Asterisk indicates apparent trend of data is the reverse of that expected.
** passive = automatic seatbelt

TABLE 5.8

Modeling for Seatbelt Subsystem Cases Studied
for Load-Strength Reliability

C. S. Davis
2-14-82
NHTSA Seatbelts

item	Vehicle	Seatbelt type	Component failure consequence behavior	model for strength y
1	Toyota Corona	Manual	Both belts fail or buckle system fails for belt system failure	$\log y = 1\beta_1 + x\beta_2 + x\beta_3 \delta_{side,pass}$
2	Toyota Corona	Manual	Weakest belt fails and other still functions	$\log y = 1\beta_1 + x\beta_2 + x\beta_3 \delta_{side,pass}$
3	Toyota Corona	redesigned passive	manual lap belt of passive system	$\log y = 1\beta_1 + x\beta_2$
4	Toyota Corona	redesigned passive	automatic shoulder belt of passive system (censored data)	$\log y = 1\beta_1 + x\beta_2 + x\beta_3 \delta_{side,pass}$
5	VW Rabbit	Manual	weakest component fails seatbelt system	$\log y = 1\beta_1 + x\beta_2$
6	VW Rabbit	passive	weakest component fails seatbelt system	$\log y = 1\beta_1 + x\beta_2$
7	VW Rabbit	redesigned passive	weakest component fails seatbelt system	$\log y = 1\beta_1 + x\beta_2$
8	Chevette	Manual passive	weakest component fails seatbelt system	$\log y = 1\beta_1 + x\beta_2$
9	Chevette	redesigned passive	weakest component fails seatbelt system (censored data)	$\log y = 1\beta_1 + x\beta_2$

Notes: passive = automatic seatbelt design
Kronecker delta $\delta_{side,pass} = 0$ for drivers side
$\delta_{side,pass} = 1$ for passenger side
x = seatbelt age in years

TABLE 5.9-1

Both Belts Fail or Buckle System Fails for Belt System Failure
Laboratory Strength Data Normalized
for Component Ranking and Seatbelt Reliability Analysis

[Marked For Manual Systems]

seat belt Lab test No.	Vehicle model year	Vehicle city	floor retractor	floor retractor to buckle Webbing	buckle	buckle to floor attach Webbing	buckle assembly floor attach	shoulder retractor	shoulder retractor to buckle Webbing	pass. or driver seat belt	Seatbelt design	Identified component failure	* if acceleration displacement test run
Toyota Corona			1.0	1.0	manual lap	-N/A-	manual lap	-N/A-	-N/A-		passive		
	Loading Factors		1.0	1.0	1.7	1.7	1.7	1.0	1.0		manual		
			2.0	1.0	1.7	1.7	1.7	-N/A-	-N/A-		dual		
1	74	Los Angeles	3750	3500	(2059)	2059	(2059)	(1950)	1950	driver	manual	webbing	
2	74	Los Angeles	4150	(4150)	–	–	–	2100	(2100)	driver	manual	retractor	
3	74	Los Angeles	3600	(3600)	–	–	–	(1900)	1900	driver	manual	retractor	
4	74	Los Angeles	(2550)	2550	–	–	–	(1650)	1650	driver	manual	retractor	
6	74	Los Angeles	4400	3150	(2500)	2500	(2500)	(1550)	1550	driver	manual	retractor	
7	74	Los Angeles	4450	(4450)	1882	1882	(1882)	1950	(1950)	pass	manual	retractor	
8	74	Los Angeles	(3400)	(3400)	2000	2000	(2000)	1800	(1800)	driver	manual	retractor	
9	74	Los Angeles	3950	3350	(2118)	2118	(2118)	2100	(2100)	driver	manual	floor mounts	
10	74	Los Angeles	3700	3150	(2176)	2176	(2176)	(2500)	2500	pass	manual	floor mounts	
5	74	Phoenix	4000	(4000)	(1882)	1882	(1882)	(1100)	1100	driver	manual	N/A	
11	75	Denver	3800	(3800)	–	–	–	2450	(2450)	pass	manual	N/A	
17	76	Phoenix	3350	(3350)	(2465)	2465	(2465)	2200	(2200)	driver	manual	Ret. Guide Ring	
18	76	Phoenix	3600	(3600)	(2118)	(2118)	(2118)	(2500)	2500	pass	manual	Ret. Guide Ring	
12	76	Denver	4050	(4050)	–	–	–	2110	(2110)	driver	manual	retractor	
13	76	Denver	4250	(4250)	–	–	–	2400	(2400)	pass	manual	retractor	
14	76	Denver	3550	(3550)	–	–	–	2500	(2500)	driver	manual	retractor	
15	76	Denver	3450	(3450)	–	–	–	2800	(2800)	driver	manual	retractor	
16	76	Denver	3700	(3700)	–	–	–	2600	(2600)	pass	manual	retractor	
19	78	Los Angeles	–	3300	(1941)	(1941)	(1941)	2300	(2300)	driver	manual	retractor	
20	78	Los Angeles	–	3700	(2176)	(2176)	(2176)	2350	(2350)	pass	manual	retractor	
21	79	Los Angeles								driver	dual	retractor	*
22	79	Los Angeles								pass	dual	retractor	*
23	NEW	pre 79	3100	(3100)	2412	2412	(2412)	2550	(2550)	–	manual	-none-	
24	NEW	pre 79	2900	(2900)	(2382)	2382	(2382)	2500	(2500)	–	manual	-none-	
25	NEW	pre 79	3950	(3950)	–	–	–	2300	(2300)	–	manual	-none-	
26	NEW	pre 79	3600	(3600)	(2588)	2588	(2588)	2800	(2800)	–	manual	-none-	
no. of fails/no. at risk			10/22	3/24	15/11	9.5/11							
Weights for data			.6906	.6331	1.3813	1.3813							

Notes: 1. Weights, W_i, for data are computed for each i^{th} component using

$$W_i = \frac{\sum_j n_{sj}}{n_{ri}} \Big/ \sum_k \frac{n_{sk}}{n_{rk}}$$

where n_{si} = no. of fails which is the number of seatbelts in which the recorded failing test load of the i^{th} component would result in the seatbelt system failure considered on the data sheet.

n_{ri} = no. at risk which is the number of seatbelts in which the i^{th} component was loaded sufficient for the seatbelt system failure in question.

2. passive = automatic seatbelt design

TABLE 5.9-2

Weakest Belt Fails and Other Still Functions
Laboratory Strength Data Normalized
for Component Ranking and Seatbelt Reliability Analysis

[Marked for Manual Systems]

Seat belt Lab test No.	Vehicle model year	Vehicle city	Floor retractor	Floor retractor to buckle Webbing	buckle	buckle to floor attach Webbing	buckle assembly floor attach	shoulder retractor	shoulder retractor to buckle Webbing	pass. or driver seat belt	seatbelt design	Identified component failure	* if acceleration displacement test run
Toyota Corona			1.0	1.0	manual Lap	-N/A-	manual Lap	-N/A-	-N/A-		passive		
	Loading Factors		1.0	1.0	1.7	1.7	1.7	1.0	1.0		manual		
			2.0	1.0	1.7	1.7	1.7	-N/A-	-N/A-		dual		
1	74	Los Angeles	3750	3500				(1950)	1950	driver	manual	webbing	
2	74	Los Angeles	4150	(4150)				2100	(2100)	driver	manual	retractor	
3	74	Los Angeles	3600	(3600)				(1900)	1900	driver	manual	retractor	
4	74	Los Angeles	(2550)	2550				(1650)	1650	driver	manual	retractor	
6	74	Los Angeles	4400	3150				(1550)	1550	driver	manual	retractor	
7	74	Los Angeles	4450	(4450)				1950	(1950)	pass	manual	retractor	
8	74	Los Angeles	(3400)	(3400)				1800	(1800)	driver	manual	retractor	
9	74	Los Angeles	3950	3350				2100	(2100)	driver	manual	Floor mounts	
10	74	Los Angeles	3700	3150				(2500)	2500	pass	manual	Floor mounts	
5	74	Phoenix	4000	(4000)				(1100)	1100	driver	manual	N/A	
11	75	Denver	3800	(3800)				2450	(2450)	pass	manual	N/A	
17	76	Phoenix	3350	(3350)				2200	(2200)	driver	manual	Ret. Guide Ring	
18	76	Phoenix	3600	(3600)				(2500)	2500	pass	manual	Ret. Guide Ring	
12	76	Denver	4050	(4050)				2110	(2110)	driver	manual	retractor	
13	76	Denver	4250	(4250)				2400	(2400)	pass	manual	retractor	
14	76	Denver	3550	(3550)				2500	(2500)	driver	manual	retractor	
15	76	Denver	3450	(3450)				2800	(2800)	driver	manual	retractor	
16	76	Denver	3700	(3700)				2600	(2600)	pass	manual	retractor	
19	78	Los Angeles	-	3300				2300	(2300)	driver	manual	retractor	
20	78	Los Angeles	-	3700				2350	(2350)	pass	manual	retractor	
21	79	Los Angeles								driver	dual	retractor	*
22	79	Los Angeles								pass	dual	retractor	*
23	NEW	pre 79	3100	(3100)				2550	(2550)	-	manual	-none-	
24	NEW	pre 79	2900	(2900)				2500	(2500)	-	manual	-none-	
25	NEW	pre 79	3950	(3950)				2300	(2300)	-	manual	-none-	
26	NEW	pre 79	3600	(3600)				2800	(2800)	-	manual	-none-	
no. of fails/no at risk								17/24	7/24				
Weights for data								1.0000	1.0000				

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TABLE 5.9-3

Manual Lap Belt of Passive System Represented by
Laboratory Strength Data Normalized
for Component Ranking and Seatbelt Reliability Analysis

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Marked for
Passive System

seat belt Lab test No.	Vehicle model year	Vehicle city	Floor retractor	Floor retractor to buckle Webbing	buckle	buckle to floor attach Webbing	buckle assembly Floor attach	shoulder retractor	shoulder retractor to buckle Webbing	pass. or driver seat belt	seatbelt design	Identified component failure	* if acceleration displacement test run
Toyota Corona			1.0	1.0	manual lap	-N/A-	manual lap	-N/A-	-N/A-		passive		
Loading Factors			1.0	1.0	1.7	1.7	1.7	1.0	1.0		manual		
			2.0	1.0	1.7	1.7	1.7	-N/A-	-N/A-		dual		
1	74	Los Angeles	3750	3500	(2059)		(2059)			driver	manual	webbing	
2	74	Los Angeles	4150	(4150)	–		–			driver	manual	retractor	
3	74	Los Angeles	3600	(3600)	–		–			driver	manual	retractor	
4	74	Los Angeles	(2550)	2550	–		–			driver	manual	retractor	
6	74	Los Angeles	4400	3150	(2500)		(2500)			driver	manual	retractor	
7	74	Los Angeles	4450	(4450)	1882		(1882)			pass	manual	retractor	
8	74	Los Angeles	(3400)	(3400)	2000		(2000)			driver	manual	retractor	
9	74	Los Angeles	3950	3350	(2118)		(2118)			driver	manual	floor mounts	
10	74	Los Angeles	3700	3150	(2176)		(2176)			pass	manual	floor mounts	
5	74	Phoenix	4000	(4000)	(1882)		(1882)			driver	manual	N/A	
11	75	Denver	3800	(3800)	–		–			pass	manual	N/A	
17	76	Phoenix	3350	(3350)	(2465)		(2465)			driver	manual	Ret. Guide Ring	
18	76	Phoenix	3600	(3600)	(2118)		(2118)			pass	manual	Ret. Guide Ring	
12	76	Denver	4050	(4050)	–		–			driver	manual	retractor	
13	76	Denver	4250	(4250)	–		–			pass	manual	retractor	
14	76	Denver	3550	(3550)	–		–			driver	manual	retractor	
15	76	Denver	3450	(3450)	–		–			driver	manual	retractor	
16	76	Denver	3700	(3700)	–		–			pass	manual	retractor	
19	78	Los Angeles	–	3300	(1941)		(1941)			driver	manual	retractor	
20	78	Los Angeles	–	3700	(2176)		(2176)			pass	manual	retractor	
21	79	Los Angeles								driver	dual	retractor	*
22	79	Los Angeles								pass	dual	retractor	*
23	NEW	pre 79	3100	(3100)	2412		(2412)			–	manual	-none-	
24	NEW	pre 79	2900	(2900)	(2382)		(2382)			–	manual	-none-	
25	NEW	pre 79	3950	(3950)	–		–			–	manual	-none-	
26	NEW	pre 79	3600	(3600)	(2588)		(2588)			–	manual	-none-	
no. of fails/no. at risk			14/22	7/24	3/3								
Weights for data			.5658	.5187	4.1493								

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TABLE 5.9-4

Passive Shoulder Belt of Passive System Represented by
Laboratory Strength Data Normalized
for Component Ranking and Seatbelt Reliability Analysis

Marked for Passive System

Seat belt Lab test No.	Vehicle model year	Vehicle city	Floor retractor	Floor retractor to buckle Webbing	buckle	buckle to floor attach Webbing	buckle assembly floor attach	shoulder retractor	shoulder retractor to buckle Webbing	pass. or driver seat belt	Seatbelt design	Identified component failure	* if acceleration displacement test run
Toyota Corona			1.0	1.0	manual Lap	-N/A-	manual Lap	-N/A-	-N/A-	Lap to retractor	passive		
Loading Factors			1.0	1.0	1.7	1.7	1.7	1.0	1.0		manual		
			2.0	1.0	1.7	1.7	1.7	-N/A-	-N/A-		dual		
1	74	Los Angeles	3750	3500						driver	manual	webbing	
2	74	Los Angeles	4150	(4150)						driver	manual	retractor	
3	74	Los Angeles	3600	(3600)						driver	manual	retractor	
4	74	Los Angeles	(2550)	2550						driver	manual	retractor	
6	74	Los Angeles	4400	3150						driver	manual	retractor	
7	74	Los Angeles	4450	(4450)						pass	manual	retractor	
8	74	Los Angeles	(3400)	(3400)						driver	manual	retractor	
9	74	Los Angeles	3950	3350						driver	manual	Floor mounts	
10	74	Los Angeles	3700	3150						pass	manual	Floor mounts	
5	74	Phoenix	4000	(4000)						driver	manual	N/A	
11	75	Denver	3800	(3800)						pass	manual	N/A	
17	76	Phoenix	3350	(3350)						driver	manual	Ret. Guide Ring	
18	76	Phoenix	3600	(3600)						pass	manual	Ret. Guide Ring	
12	76	Denver	4050	(4050)						driver	manual	retractor	
13	76	Denver	4250	(4250)						pass	manual	retractor	
14	76	Denver	3550	(3550)						driver	manual	retractor	
15	76	Denver	3450	(3450)						driver	manual	retractor	
16	76	Denver	3700	(3700)						pass	manual	retractor	
19	78	Los Angeles	-	3300						driver	manual	retractor	
20	78	Los Angeles	-	3700						pass	manual	retractor	
21	79	Los Angeles								driver	dual	retractor	*
22	79	Los Angeles								pass	dual	retractor	*
23	NEW	pre 79	3100	(3100)						-	manual	-none-	
24	NEW	pre 79	2900	(2900)						-	manual	-none-	
25	NEW	pre 79	3950	(3950)						-	manual	-none-	
26	NEW	pre 79	3600	(3600)						-	manual	-none-	
no. of fails/no. at risk			16+.5/22	7+.5/24									
Weights for data			1.0267	.9412									

Expected failure load censored data: 4206 4206

weight = .5 + .5 × weights: .2983 .2734 ⇒ .5717 weight for both components

} based on Floor retractor and Floor retractor to buckle webbing minimum loads for 74 Los Angeles

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TABLE 5.9-5

Manual Seatbelt System
Laboratory Strength Data Normalized
for Component Ranking and Seatbelt Reliability Analysis

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[Marked for Manual Systems]

Seat belt Lab test No.	Vehicle model year	Vehicle city	Retractor	retractor to floor or buckle Webbing	Buckle	buckle to floor attach Web/Cable	buckle assembly Floor attach	second floor attach	passenger or driver's seatbelt	Seatbelt design	Identified Component Failure	* if acceleration displacement test run
	VW Rabbit											
	Loading factors		1.0 1.0	1.0 1.0	1.7 1.0	1.7 —N/A—	1.7 1.0	1.0 —N/A—		manual passive		
36	75	Denver	1950	3500	(2941)	2941	(2941)	(3500)	driver		retractor	*
37	75	Denver	1350	5100	2941	(2941)	(2941)	3500	passenger		retractor	
40	75	Denver	~~3350~~	3550	3500	(3500)	(3500)	(3550)	driver		retractor	
41	75	Denver	~~2450~~	3350	(3059)	3059	(3059)	(3350)	passenger		retractor	
38	75	Houston	2850	3350	4600	N/A	(3350)	N/A	driver	passive	Ret, Buckle	*
39	75	Houston	3500	3150	(3150)	N/A	(3150)	N/A	passenger	passive	Ret, Buckle	*
42	76	Los Angeles	1500	3750	—	—	—	(3750)	driver		retractor	
43	76	Los Angeles	1650	3800	—	—	—	(3800)	passenger		retractor	*
44	76	Denver	~~1800~~	3300	—	—	—	(3300)	driver		retractor	
45	77	Phoenix	~~2400~~	3300	—	—	—	(3300)	driver		Ret/Adjust Ring	
49	79	Los Angeles	3650	3650	4200	N/A	(4200)	N/A	driver	passive	retractor	*
50	79	Los Angeles	3500	3500	4550	N/A	(4550)	N/A	passenger	passive	retractor	*
46	79	Denver	~~2400~~	4600	—	—	—	(4600)	driver		retractor	*
47	79	Houston	2950	3700	3750	N/A	(3750)	N/A	driver	passive	retractor	*
48	79	Houston	3150	3550	4250	N/A	(4250)	N/A	passenger	passive	retractor	*
51	NEW		4050	3400	—	—	—	(3400)	—		-none-	
52	NEW		1800	3950	2618	(2618)	(2618)	(3950)	—		-none-	
53	NEW		2000	3600	4450	N/A	(4450)	N/A	—	passive	-none-	
no. of fails/no. at risk			10/13	6/18	1/12	1/5						
Weights for data			.9991	.7216	1.0823	2.5971						
	Chevette											
	Loading factors		1.0 1.7	1.0 1.7	1.7 1.0	1.7 1.0	1.7 1.0	1.0 —N/A—	1.0 = no shoulder 2nd Web	manual passive		
28	76	Los Angeles	~~3150~~	2900	(2235)	(2235)	(2235)	(2900)	driver		retractor	
30	76	Los Angeles	3550	3800	(2235)	(2235)	(2235)	(3800)	driver		retractor	
27	76	Phoenix	~~3300~~	3800	(2235)	2235	(2235)	(3800)	driver		frayed belts	
29	76	Phoenix	3300	3300	(1941)	(1941)	(1941)	(4150)	driver		retractor	*
31	76	Denver	~~3200~~	3700	2147	(2147)	(2147)	4100	driver		retractor	
32	76	Denver	3500	3400	1824	(1824)	(1824)	(3400)	passenger		retractor	*
33	NEW		3600	4100	(2147)	2147	(2147)	(4100)	—		-none-	*
34	NEW		4850	4000	(2147)	2147	(2147)	(4000)	—		-none-	
35	NEW		—	(2353)	(4000)	4000	(4000)	N/A	—	passive	-none-	
35.5	NEW		—	(1971)	(3350)	3350	(3350)	N/A	—	passive	-none-	
no. of fails/no. at risk			1.5/5	1.5/8	2/7	5/7						
Weights for data			1.3445	.8403	.9604	.9604						

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TABLE 5.9 - 6,8

Automatic Seatbelt System
Laboratory Strength Data Normalized
for Component Ranking and Seatbelt Reliability Analysis

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[Marked for Passive Systems]

Seat belt Lab test No.	Vehicle model year	Vehicle City	Retractor	retractor to floor or buckle Webbing	Buckle	buckle to floor attach Web/Cable	buckle assembly Floor attach	second floor attach	passenger or driver's seatbelt	Seatbelt design	Identified Component Failure	* if acceleration displacement test run
	VW Rabbit											
	Loading Factors		1.0 1.0	1.0 1.0	1.7 1.0	1.7 —N/A—	1.7 1.0	1.0 —N/A—		manual passive		
36	75	Denver	1950	3500	(2941)		(2941)		driver		retractor	*
37	75	Denver	1350	5100	2941		(2941)		passenger		retractor	
40	75	Denver	~~3350~~	3550	3500		(3500)		driver		retractor	
41	75	Denver	~~2450~~	3350	(3059)		(3059)		passenger		retractor	
38	75	Houston	2850	3350	4600		(3350)		driver	passive	Ret., Buckle	*
39	75	Houston	3500	3150	(3150)		(3150)		passenger	passive	Ret., Buckle	*
42	76	Los Angeles	1500	3750	—		—		driver		retractor	
43	76	Los Angeles	1650	3800	—		—		passenger		retractor	*
44	76	Denver	~~1300~~	3300	—		—		driver		retractor	
45	77	Phoenix	~~2400~~	3300	—		—		driver		Ret/Adjust Ring	
49	79	Los Angeles	3650	3650	4200		(4200)		driver	passive	retractor	*
50	79	Los Angeles	3500	3500	4550		(4550)		passenger	passive	retractor	*
46	79	Denver	~~2400~~	4600	—		—		driver		retractor	*
47	79	Houston	2950	3700	3750		(3750)		driver	passive	retractor	*
48	79	Houston	3150	3550	4250		(4250)		passenger	passive	retractor	*
51	NEW		4050	3400	—		—		—		-none-	
52	NEW		1800	3950	2618		(2618)		—		-none-	
53	NEW		2000	3600	4450		(4450)		—	passive	-none-	
	no. of Fails/no. at risk		10/13	7/18	1/11							
	Weights for data		1.1086	.8006	1.3098							
	Chevette											
	Loading Factors		1.0 1.7	1.0 1.7	1.7 1.0	1.7 1.0	1.7 1.0	1.0 —N/A—	1.0 = shoulder 2nd Web	manual passive		
28	76	Los Angeles	~~3150~~	2900	(2235)	(2235)	(2235)		driver		retractor	
30	76	Los Angeles	3550	3800	(2235)	(2235)	(2235)		driver		retractor	
27	76	Phoenix	~~3300~~	3800	(2235)	2235	(2235)		driver		frayed Belts	
29	76	Phoenix	3300	3300	(1941)	(1941)	(1941)		driver		retractor	*
31	76	Denver	~~3200~~	3700	2147	(2147)	(2147)		driver		retractor	
32	76	Denver	3500	3400	1824	(1824)	(1824)		passenger		retractor	*
33	NEW		3600	4100	(2147)	2147	(2147)		—		-none-	*
34	NEW		4850	4000	(2147)	2147	(2147)		—		-none-	
35	NEW		—	(2353)	(4000)	4000	(4000)		—	passive	-none-	
35.5	NEW		—	(1971)	(3350)	3350	(3350)		—	passive	-none-	
	no. of Fails/no. at risk		1.5/5	1.5/8	2/7	5/7						
	Weights for data		1.3445	.8403	.9604	.9604						

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TABLE 5.9 - 7,9

Redesigned Automatic Seatbelt System
Laboratory Strength Data Normalized
for Component Ranking and Seatbelt Reliability Analysis

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[Redesigned Passive Systems]

Seat belt Lab test No.	Vehicle model year	Vehicle city	Retractor	retractor to floor or buckle Webbing	Buckle	buckle to floor attach Web/Cable	buckle assembly floor attach	second floor attach	passenger or driver's seatbelt	Seatbelt design	Identified Component Failure	* if acceleration displacement test run
	VW Rabbit											
	Loading factors		1.0 1.0	1.0 1.0	1.7 1.0	1.7 —N/A—	1.7 1.0	1.0 —N/A—		manual passive		
36	75	Denver		3500	(2941)		(2941)		driver		retractor	*
37	75	Denver		5100	2941		(2941)		passenger		retractor	
40	75	Denver		3550	3500		(3500)		driver		retractor	
41	75	Denver		3350	(3059)		(3059)		passenger		retractor	
38	75	Houston		3350	4600		(3350)		driver	passive	Ret, Buckle	*
39	75	Houston		3150	(3150)		(3150)		passenger	passive	Ret, Buckle	*
42	76	Los Angeles		3750	—		—		driver		retractor	
43	76	Los Angeles		3800	—		—		passenger		retractor	*
44	76	Denver		3300	—		—		driver		retractor	
45	77	Phoenix		3300	—		—		driver		Ret/Adjust Ring	
49	79	Los Angeles		3650	4200		(4200)		driver	passive	retractor	*
50	79	Los Angeles		3500	4550		(4550)		passenger	passive	retractor	*
46	79	Denver		4600	—		—		driver		retractor	*
47	79	Houston		3700	3750		(3750)		driver	passive	retractor	*
48	79	Houston		3550	4250		(4250)		passenger	passive	retractor	*
51	NEW			3400	—		—		—		-none-	
52	NEW			3950	2618		(2618)		—		-none-	
53	NEW			3600	4450		(4450)		—	passive	-none-	
no. of Fails/no. at risk Weights for data			replaced	15/18 .8824	3/10 1.5880							
	Chevette											
	Loading factors		1.0 1.7	1.0 1.7	1.7 1.0	1.7 1.0	1.7 1.0	1.0 —N/A—	LO = shoulder 2nd Web	manual passive		
28	76	Los Angeles	~~3150~~	2900	(2235)		(2235)		driver		retractor	
30	76	Los Angeles	3550	3800	(2235)		(2235)		driver		retractor	
27	76	Phoenix	~~3300~~	3800	(2235)		(2235)		driver		frayed belts	
29	76	Phoenix	3300	3300	(1941)		(1941)		driver		retractor	*
31	76	Denver	~~3200~~	3700	2147		(2147)		driver		retractor	
32	76	Denver	3500	3400	1824		(1824)		passenger		retractor	*
33	NEW		3600	4100	(2147)		(2147)		—		-none-	*
34	NEW		4850	4000	(2147)		(2147)		—		-none-	
35	NEW		—	(2353)	(4000)		(4000)		—	passive	-none-	
35.5	NEW		—	(1971)	(3350)		(3350)		—	passive	-none-	
no. of Fails/no. at risk Weights for data			2.5/5 1.1461	3.5+1/10 .5731	2+.7/4 1.4327	replaced	0+.6/4 1.4327					
Expected failure load censored data weight = .311 × weights proportion				2425 .1248	4122 .3119		4122 .2673		} based on retractor to floor or buckle webbing loads on NEW Chevette belts			

TABLE 5.10

Least Squares Solution, Analysis of Variance, and Analysis of Residuals for Modeling Applied to Seatbelt Strength Data

```
EXPERIMENT DESIGN CHECK + LEAST SQUARE SOLUTION OF LINEAR EQUATIONS Y=X*B+ERROR.
     IN IPRINT(1): PUT 1 TO OR 0 NOT TO WRITE INPUT INSTRUCTIONS
        IPRINT(2):     1 TO OR 0 NOT TO WRITE REPEATED RESULTS
     FOLLOW EACH ENTRY WITH A COMMA.

1.  TOYOTA MANUAL BELT --- BOTH BELTS OR BUCKLE SYSTEM FAILS FOR SYSTEM FAILURE
    FOR INPUT INSTRUCTION IPRINT(1)= 0    FOR REPEAT RESULTS IPRINT(2)= 0
    FOR DIAGNOSTIC OUTPUT NPRINT= 0  FOR THE MAIN ROUTINE
                                  0  FOR SUBROUTINE OBSERV
                                  0  FOR SUBROUTINE INVERT
                                  0  FOR SUBROUTINE RESID
    INS=-1    INX= 1    INY= 1        INW= 1    INR= 1         M= 24     N=  3
```

Failure
Analysis
Associates
FAA-82-2-14

TABLE 5.10-1

LEAST SQUARE SOLUTION OF LINEAR EQUATIONS Y=X*B+ERROR
1. TOYOTA MANUAL BELT --- BOTH BELTS OR BUCKLE SYSTEM FAILS FOR SYSTEM FAILURE

ITEM	WEIGHTING	ALLOCATION MATRIX OF COEFFICIENTS X(I,J)		
1	1.3813	0.10000E 01	0.70000E 01	0.00000E 00
2	0.6906	0.10000E 01	0.70000E 01	0.00000E 00
3	0.6906	0.10000E 01	0.70000E 01	0.00000E 00
4	0.6331	0.10000E 01	0.70000E 01	0.00000E 00
5	1.3813	0.10000E 01	0.70000E 01	0.00000E 00
6	1.3813	0.10000E 01	0.70000E 01	0.10000E 01
7	1.3813	0.10000E 01	0.70000E 01	0.00000E 00
8	1.3813	0.10000E 01	0.70000E 01	0.00000E 00
9	1.3813	0.10000E 01	0.70000E 01	0.10000E 01
10	1.3813	0.10000E 01	0.70000E 01	0.00000E 00
11	0.6906	0.10000E 01	0.60000E 01	0.10000E 01
12	1.3813	0.10000E 01	0.50000E 01	0.00000E 00
13	0.6906	0.10000E 01	0.50000E 01	0.10000E 01
14	0.6906	0.10000E 01	0.50000E 01	0.00000E 00
15	0.6906	0.10000E 01	0.50000E 01	0.10000E 01
16	0.6906	0.10000E 01	0.50000E 01	0.00000E 00
17	0.6906	0.10000E 01	0.50000E 01	0.00000E 00
18	0.6906	0.10000E 01	0.50000E 01	0.10000E 01
19	0.6331	0.10000E 01	0.30000E 01	0.00000E 00
20	0.6331	0.10000E 01	0.30000E 01	0.10000E 01
21	1.3813	0.10000E 01	0.00000E 00	0.00000E 00
22	1.3813	0.10000E 01	0.00000E 00	0.00000E 00
23	0.6906	0.10000E 01	0.00000E 00	0.00000E 00
24	1.3813	0.10000E 01	0.00000E 00	0.00000E 00

ANALYSIS OF VARIANCE BASED ON NATURAL LOG OF OBSERVATIONS

SUM SQUARES	MEAN SQUARE	DEGREES OF FREEDOM
0.14496E 01	0.69029E-01	0.21000E 02

TERM	ESTIMATES	INVERSE OF PRODUCT MATRIX (X'X)**-1		
1	0.79755E 01	0.18199E 00		
2	-0.25534E-01	-0.27533E-01	0.60191E-02	
3	0.71745E-01	-0.22196E-01	-0.74008E-02	0.22754E 00

CONDITION(MIN EIGNVAL/MAX EIGNVAL) OF TRIANGULAR MATRIX: COND=0.1594E 00
DETERMINANT OF NORMALIZED INFORMATION MATRIX-PRODUCT X'X: DET=0.1654E 00

ANALYSIS OF RESIDUALS FOR CURRENT DATA ONLY

ITEM	WEIGHTING	OBSERVATION	PREDICTION	RESIDUAL	ITEM
1	1.3813	0.20590E 04	0.24327E 04	-0.37367E 03	1
2	0.6906	0.41500E 04	0.24327E 04	0.17173E 04	2
3	0.6906	0.36000E 04	0.24327E 04	0.11673E 04	3
4	0.6331	0.25500E 04	0.24327E 04	0.11733E 03	4
5	1.3813	0.25000E 04	0.24327E 04	0.67333E 02	5
6	1.3813	0.18820E 04	0.26136E 04	-0.73161E 03	6
7	1.3813	0.20000E 04	0.24327E 04	-0.43267E 03	7
8	1.3813	0.21180E 04	0.24327E 04	-0.31467E 03	8
9	1.3813	0.21760E 04	0.26136E 04	-0.43761E 03	9
10	1.3813	0.18820E 04	0.24327E 04	-0.55067E 03	10
11	0.6906	0.38000E 04	0.26812E 04	0.11188E 04	11
12	1.3813	0.24650E 04	0.25601E 04	-0.95124E 02	12
13	0.6906	0.36000E 04	0.27505E 04	0.84945E 03	13
14	0.6906	0.40500E 04	0.25601E 04	0.14899E 04	14
15	0.6906	0.24500E 04	0.27505E 04	-0.30055E 03	15
16	0.6906	0.35500E 04	0.25601E 04	0.98988E 03	16
17	0.6906	0.34500E 04	0.25601E 04	0.88987E 03	17
18	0.6906	0.37000E 04	0.27505E 04	0.94945E 03	18
19	0.6331	0.33000E 04	0.26943E 04	0.60573E 03	19
20	0.6331	0.37000E 04	0.28947E 04	0.80533E 03	20
21	1.3813	0.24120E 04	0.29088E 04	-0.49676E 03	21
22	1.3813	0.23820E 04	0.29088E 04	-0.52676E 03	22
23	0.6906	0.39500E 04	0.29088E 04	0.10412E 04	23
24	1.3813	0.25860E 04	0.29088E 04	-0.32076E 03	24

TABLE 5.10-2

LEAST SQUARE SOLUTION OF LINEAR EQUATIONS Y=X*B+ERROR
2. TOYOTA MANUAL BELT --- WEAKEST BELT FAILS AND OTHER STILL FUNCTIONS

ITEM	WEIGHTING	ALLOCATION MATRIX OF COEFFICIENTS X(I,J)		
1	1.0000	0.10000E 01	0.70000E 01	0.00000E 00
2	1.0000	0.10000E 01	0.70000E 01	0.00000E 00
3	1.0000	0.10000E 01	0.70000E 01	0.00000E 00
4	1.0000	0.10000E 01	0.70000E 01	0.00000E 00
5	1.0000	0.10000E 01	0.70000E 01	0.00000E 00
6	1.0000	0.10000E 01	0.70000E 01	0.10000E 01
7	1.0000	0.10000E 01	0.70000E 01	0.00000E 00
8	1.0000	0.10000E 01	0.70000E 01	0.00000E 00
9	1.0000	0.10000E 01	0.70000E 01	0.10000E 01
10	1.0000	0.10000E 01	0.70000E 01	0.00000E 00
11	1.0000	0.10000E 01	0.60000E 01	0.10000E 01
12	1.0000	0.10000E 01	0.50000E 01	0.00000E 00
13	1.0000	0.10000E 01	0.50000E 01	0.10000E 01
14	1.0000	0.10000E 01	0.50000E 01	0.00000E 00
15	1.0000	0.10000E 01	0.50000E 01	0.10000E 01
16	1.0000	0.10000E 01	0.50000E 01	0.00000E 00
17	1.0000	0.10000E 01	0.50000E 01	0.00000E 00
18	1.0000	0.10000E 01	0.50000E 01	0.10000E 01
19	1.0000	0.10000E 01	0.30000E 01	0.00000E 00
20	1.0000	0.10000E 01	0.30000E 01	0.10000E 01
21	1.0000	0.10000E 01	0.00000E 00	0.00000E 00
22	1.0000	0.10000E 01	0.00000E 00	0.00000E 00
23	1.0000	0.10000E 01	0.00000E 00	0.00000E 00
24	1.0000	0.10000E 01	0.00000E 00	0.00000E 00

ANALYSIS OF VARIANCE BASED ON NATURAL LOG OF OBSERVATIONS

SUM SQUARES	MEAN SQUARE	DEGREES OF FREEDOM
0.58419E 00	0.27818E-01	0.21000E 02

TERM	ESTIMATES	INVERSE OF PRODUCT MATRIX (X'X)**-1		
1	0.78718E 01	0.20714E 00		
2	-0.49930E-01	-0.31917E-01	0.68683E-02	
3	0.17584E 00	-0.33880E-01	-0.53677E-02	0.20588E 00

CONDITION(MIN EIGNVAL/MAX EIGNVAL) OF TRIANGULAR MATRIX: COND=0.1808E 00
DETERMINANT OF NORMALIZED INFORMATION MATRIX-PRODUCT X'X: DET=0.1434E 00

ANALYSIS OF RESIDUALS FOR CURRENT DATA ONLY

ITEM	WEIGHTING	OBSERVATION	PREDICTION	RESIDUAL	ITEM
1	1.0000	0.19500E 04	0.18488E 04	0.10124E 03	1
2	1.0000	0.21000E 04	0.18488E 04	0.25124E 03	2
3	1.0000	0.19000E 04	0.18488E 04	0.51242E 02	3
4	1.0000	0.16500E 04	0.18488E 04	-0.19876E 03	4
5	1.0000	0.15500E 04	0.18488E 04	-0.29876E 03	5
6	1.0000	0.19500E 04	0.22042E 04	-0.25418E 03	6
7	1.0000	0.18000E 04	0.18488E 04	-0.48757E 02	7
8	1.0000	0.21000E 04	0.18488E 04	0.25124E 03	8
9	1.0000	0.25000E 04	0.22042E 04	0.29582E 03	9
10	1.0000	0.11000E 04	0.18488E 04	-0.74876E 03	10
11	1.0000	0.24500E 04	0.23170E 04	0.13297E 03	11
12	1.0000	0.22000E 04	0.20429E 04	0.15709E 03	12
13	1.0000	0.25000E 04	0.24357E 04	0.64346E 02	13
14	1.0000	0.21100E 04	0.20429E 04	0.67093E 02	14
15	1.0000	0.24000E 04	0.24357E 04	-0.35654E 02	15
16	1.0000	0.25000E 04	0.20429E 04	0.45709E 03	16
17	1.0000	0.28000E 04	0.20429E 04	0.75709E 03	17
18	1.0000	0.26000E 04	0.24357E 04	0.16435E 03	18
19	1.0000	0.23000E 04	0.22574E 04	0.42553E 02	19
20	1.0000	0.23500E 04	0.26914E 04	-0.34144E 03	20
21	1.0000	0.25500E 04	0.26222E 04	-0.72229E 02	21
22	1.0000	0.25000E 04	0.26222E 04	-0.12223E 03	22
23	1.0000	0.23000E 04	0.26222E 04	-0.32223E 03	23
24	1.0000	0.28000E 04	0.26222E 04	0.17777E 03	24

TABLE 5.10-3

LEAST SQUARE SOLUTION OF LINEAR EQUATIONS Y=X*B+ERROR
3. TOYOTA REDESIGNED PASSIVE BELT --- MANUAL LAP BELT OF SYSTEM

ITEM	WEIGHTING	ALLOCATION MATRIX OF COEFFICIENTS X(I,J)	
1	0.5187	0.10000E 01	0.70000E 01
2	0.5658	0.10000E 01	0.70000E 01
3	0.5658	0.10000E 01	0.70000E 01
4	0.5187	0.10000E 01	0.70000E 01
5	0.5187	0.10000E 01	0.70000E 01
6	4.1493	0.10000E 01	0.70000E 01
7	4.1493	0.10000E 01	0.70000E 01
8	0.5187	0.10000E 01	0.70000E 01
9	0.5187	0.10000E 01	0.70000E 01
10	0.5658	0.10000E 01	0.70000E 01
11	0.5658	0.10000E 01	0.60000E 01
12	0.5658	0.10000E 01	0.50000E 01
13	0.5658	0.10000E 01	0.50000E 01
14	0.5658	0.10000E 01	0.50000E 01
15	0.5658	0.10000E 01	0.50000E 01
16	0.5658	0.10000E 01	0.50000E 01
17	0.5658	0.10000E 01	0.50000E 01
18	0.5658	0.10000E 01	0.50000E 01
19	0.5187	0.10000E 01	0.30000E 01
20	0.5187	0.10000E 01	0.30000E 01
21	4.1593	0.10000E 01	0.00000E 00
22	0.5658	0.10000E 01	0.00000E 00
23	0.5658	0.10000E 01	0.00000E 00
24	0.5658	0.10000E 01	0.00000E 00

ANALYSIS OF VARIANCE BASED ON NATURAL LOG OF OBSERVATIONS

SUM SQUARES	MEAN SQUARE	DEGREES OF FREEDOM
0.19111E 01	0.86827E-01	0.22010E 02

TERM	ESTIMATES	INVERSE OF PRODUCT MATRIX (X'X)**-1	
1	0.79828E 01	0.15513E 00	
2	-0.17909E-01	-0.23810E-01	0.49956E-02

CONDITION(MIN EIGNVAL/MAX EIGNVAL) OF TRIANGULAR MATRIX: CONO=0.3463E 00
DETERMINANT OF NORMALIZED INFORMATION MATRIX-PRODUCT X'X: DET=0.2685E 00

ANALYSIS OF RESIDUALS FOR CURRENT DATA ONLY

ITEM	WEIGHTING	OBSERVATION	PREDICTION	RESIDUAL	ITEM
1	0.5187	0.35000E 04	0.25850E 04	0.91502E 03	1
2	0.5658	0.41500E 04	0.25850E 04	0.15650E 04	2
3	0.5658	0.36000E 04	0.25850E 04	0.10150E 04	3
4	0.5187	0.25500E 04	0.25850E 04	-0.34975E 02	4
5	0.5187	0.31500E 04	0.25850E 04	0.56503E 03	5
6	4.1493	0.18820E 04	0.25850E 04	-0.70297E 03	6
7	4.1493	0.20000E 04	0.25850E 04	-0.58498E 03	7
8	0.5187	0.33500E 04	0.25850E 04	0.76503E 03	8
9	0.5187	0.31500E 04	0.25850E 04	0.56503E 03	9
10	0.5658	0.40000E 04	0.25850E 04	0.14150E 04	10
11	0.5658	0.38000E 04	0.26317E 04	0.11683E 04	11
12	0.5658	0.33500E 04	0.26792E 04	0.67076E 03	12
13	0.5658	0.36000E 04	0.26792E 04	0.92076E 03	13
14	0.5658	0.40500E 04	0.26792E 04	0.13708E 04	14
15	0.5658	0.42500E 04	0.26792E 04	0.15708E 04	15
16	0.5658	0.35500E 04	0.26792E 04	0.87076E 03	16
17	0.5658	0.34500E 04	0.26792E 04	0.77076E 03	17
18	0.5658	0.37000E 04	0.26792E 04	0.10208E 04	18
19	0.5187	0.33000E 04	0.27769E 04	0.52305E 03	19
20	0.5187	0.37000E 04	0.27769E 04	0.92305E 03	20
21	4.1593	0.24120E 04	0.29302E 04	-0.51822E 03	21
22	0.5658	0.29000E 04	0.29302E 04	-0.30225E 02	22
23	0.5658	0.39500E 04	0.29302E 04	0.10198E 04	23
24	0.5658	0.36000E 04	0.29302E 04	0.66977E 03	24

TABLE 5.10-4

LEAST SQUARE SOLUTION OF LINEAR EQUATIONS Y=X*B+ERROR
4. TOYOTA REDESIGNED PASSIVE BELT --- AUTOMATIC SHOULDER BELT OF SYSTEM

ITEM	WEIGHTING	ALLOCATION MATRIX OF COEFFICIENTS X(I,J)		
1	0.9412	0.10000E 01	0.70000E 01	0.00000E 00
2	1.0267	0.10000E 01	0.70000E 01	0.00000E 00
3	1.0267	0.10000E 01	0.70000E 01	0.00000E 00
4	0.9412	0.10000E 01	0.70000E 01	0.00000E 00
5	0.9412	0.10000E 01	0.70000E 01	0.00000E 00
6	1.0267	0.10000E 01	0.70000E 01	0.10000E 01
7	0.5717	0.10000E 01	0.70000E 01	0.00000E 00
8	0.9412	0.10000E 01	0.70000E 01	0.00000E 00
9	0.9412	0.10000E 01	0.70000E 01	0.10000E 01
10	1.0267	0.10000E 01	0.70000E 01	0.00000E 00
11	1.0267	0.10000E 01	0.60000E 01	0.10000E 01
12	1.0267	0.10000E 01	0.50000E 01	0.00000E 00
13	1.0267	0.10000E 01	0.50000E 01	0.10000E 01
14	1.0267	0.10000E 01	0.50000E 01	0.00000E 00
15	1.0267	0.10000E 01	0.50000E 01	0.10000E 01
16	1.0267	0.10000E 01	0.50000E 01	0.00000E 00
17	1.0267	0.10000E 01	0.50000E 01	0.00000E 00
18	1.0267	0.10000E 01	0.50000E 01	0.10000E 01
19	0.9412	0.10000E 01	0.30000E 01	0.00000E 00
20	0.9412	0.10000E 01	0.30000E 01	0.10000E 01
21	1.0267	0.10000E 01	0.00000E 00	0.00000E 00
22	1.0267	0.10000E 01	0.00000E 00	0.00000E 00
23	1.0267	0.10000E 01	0.00000E 00	0.00000E 00
24	1.0267	0.10000E 01	0.00000E 00	0.00000E 00

ANALYSIS OF VARIANCE BASED ON NATURAL LOG OF OBSERVATIONS

SUM SQUARES	MEAN SQUARE	DEGREES OF FREEDOM
0.33652E 00	0.16346E-01	0.20587E 02

TERM	ESTIMATES	INVERSE OF PRODUCT MATRIX (X'X)**-1		
1	0.81250E 01	0.20369E 00		
2	0.63906E-02	-0.31558E-01	0.69473E-02	
3	0.81902E-01	-0.32050E-01	-0.62290E-02	0.20846E 00

CONDITION(MIN EIGNVAL/MAX EIGNVAL) OF TRIANGULAR MATRIX: COND=0.1801E 00
DETERMINANT OF NORMALIZED INFORMATION MATRIX-PRODUCT X'X: DET=0.1458E 00

ANALYSIS OF RESIDUALS FOR CURRENT DATA ONLY

ITEM	WEIGHTING	OBSERVATION	PREDICTION	RESIDUAL	ITEM
1	0.9412	0.35000E 04	0.35324E 04	-0.32409E 02	1
2	1.0267	0.41500E 04	0.35324E 04	0.61759E 03	2
3	1.0267	0.36000E 04	0.35324E 04	0.67589E 02	3
4	0.9412	0.25500E 04	0.35324E 04	-0.98241E 03	4
5	0.9412	0.31500E 04	0.35324E 04	-0.38241E 03	5
6	1.0267	0.44500E 04	0.38339E 04	0.61610E 03	6
7	0.5717	0.42060E 04	0.35324E 04	0.67359E 03	7
8	0.9412	0.33500E 04	0.35324E 04	-0.18241E 03	8
9	0.9412	0.31500E 04	0.38339E 04	-0.68390E 03	9
10	1.0267	0.40000E 04	0.35324E 04	0.46759E 03	10
11	1.0267	0.38000E 04	0.38095E 04	-0.94741E 01	11
12	1.0267	0.33500E 04	0.34875E 04	-0.13755E 03	12
13	1.0267	0.36000E 04	0.37852E 04	-0.18521E 03	13
14	1.0267	0.40500E 04	0.34875E 04	0.56245E 03	14
15	1.0267	0.42500E 04	0.37852E 04	0.46479E 03	15
16	1.0267	0.35500E 04	0.34375E 04	0.62452E 02	16
17	1.0267	0.34500E 04	0.34875E 04	-0.37550E 02	17
18	1.0267	0.37000E 04	0.37852E 04	-0.85208E 02	18
19	0.9412	0.33000E 04	0.34433E 04	-0.14326E 03	19
20	0.9412	0.37000E 04	0.37371E 04	-0.37136E 02	20
21	1.0267	0.31000E 04	0.33779E 04	-0.27787E 03	21
22	1.0267	0.29000E 04	0.33779E 04	-0.47787E 03	22
23	1.0267	0.39500E 04	0.33779E 04	0.57213E 03	23
24	1.0267	0.36000E 04	0.33779E 04	0.22213E 03	24

TABLE 5.10-5

LEAST SQUARE SOLUTION OF LINEAR EQUATIONS Y=X*B+ERROR
5. RABBIT MANUAL BELT --- WEAKEST COMPONENT FAILS SEATBELT SYSTEM

ITEM	WEIGHTING	ALLOCATION MATRIX OF COEFFICIENTS X(I,J)	
1	0.9991	0.10000E 01	0.60000E 01
2	0.9991	0.10000E 01	0.60000E 01
3	1.0823	0.10000E 01	0.60000E 01
4	2.5971	0.10000E 01	0.60000E 01
5	0.9991	0.10000E 01	0.60000E 01
6	0.7216	0.10000E 01	0.60000E 01
7	0.9991	0.10000E 01	0.50000E 01
8	0.9991	0.10000E 01	0.50000E 01
9	0.7216	0.10000E 01	0.50000E 01
10	0.7216	0.10000E 01	0.40000E 01
11	0.8604	0.10000E 01	0.20000E 01
12	0.8604	0.10000E 01	0.20000E 01
13	0.7216	0.10000E 01	0.20000E 01
14	0.9991	0.10000E 01	0.20000E 01
15	0.9991	0.10000E 01	0.20000E 01
16	0.7216	0.10000E 01	0.00000E 00
17	0.9991	0.10000E 01	0.00000E 00
18	0.9991	0.10000E 01	0.00000E 00

RESULTS FROM ANALYSIS OF CURRENT EXPERIMENT

ANALYSIS OF VARIANCE BASED ON NATURAL LOG OF OBSERVATIONS

SUM SQUARES	MEAN SQUARE	DEGREES OF FREEDOM
0.19947E 01	0.12467E 00	0.16000E 02

TERM	ESTIMATES	INVERSE OF PRODUCT MATRIX (X'X)**-1	
1	0.79396E 01	0.21650E 00	
2	-0.16642E-01	-0.41531E-01	0.10717E-01

CONDITION(MIN EIGNVAL/MAX EIGNVAL) OF TRIANGULAR MATRIX: COND=0.4392E 00
DETERMINANT OF NORMALIZED INFORMATION MATRIX-PRODUCT X'X: DET=0.2566E 00

ANALYSIS OF RESIDUALS FOR CURRENT DATA ONLY

ITEM	WEIGHTING	OBSERVATION	PREDICTION	RESIDUAL	ITEM
1	0.9991	0.19500E 04	0.25395E 04	-0.58955E 03	1
2	0.9991	0.13500E 04	0.25395E 04	-0.11895E 04	2
3	1.0823	0.35000E 04	0.25395E 04	0.96045E 03	3
4	2.5971	0.30590E 04	0.25395E 04	0.51945E 03	4
5	0.9991	0.28500E 04	0.25395E 04	0.31045E 03	5
6	0.7216	0.31500E 04	0.25395E 04	0.61045E 03	6
7	0.9991	0.15000E 04	0.25822E 04	-0.10822E 04	7
8	0.9991	0.16500E 04	0.25822E 04	-0.93216E 03	8
9	0.7216	0.33000E 04	0.25822E 04	0.71784E 03	9
10	0.7216	0.33000E 04	0.26255E 04	0.67450E 03	10
11	0.8604	0.36500E 04	0.27143E 04	0.93565E 03	11
12	0.8604	0.35000E 04	0.27143E 04	0.78565E 03	12
13	0.7216	0.46000E 04	0.27143E 04	0.18856E 04	13
14	0.9991	0.29500E 04	0.27143E 04	0.23565E 03	14
15	0.9991	0.31500E 04	0.27143E 04	0.43565E 03	15
16	0.7216	0.34000E 04	0.28062E 04	0.59379E 03	16
17	0.9991	0.18000E 04	0.28062E 04	-0.10062E 04	17
18	0.9991	0.20000E 04	0.28062E 04	-0.80621E 03	18

TABLE 5.10-6

LEAST SQUARE SOLUTION OF LINEAR EQUATIONS Y=X*B+ERROR
6. RABBIT PASSIVE BELT --- WEAKEST COMPONENT FAILS SEATBELT SYSTEM

ITEM	WEIGHTING	ALLOCATION MATRIX OF COEFFICIENTS X(I,J)	
1	1.1086	0.10000E 01	0.60000E 01
2	1.1086	0.10000E 01	0.60000E 01
3	1.3098	0.10000E 01	0.60000E 01
4	0.8006	0.10000E 01	0.60000E 01
5	1.1086	0.10000E 01	0.60000E 01
6	0.8006	0.10000E 01	0.60000E 01
7	1.1086	0.10000E 01	0.50000E 01
8	1.1086	0.10000E 01	0.50000E 01
9	0.8006	0.10000E 01	0.50000E 01
10	0.8006	0.10000E 01	0.40000E 01
11	0.9546	0.10000E 01	0.20000E 01
12	0.9546	0.10000E 01	0.20000E 01
13	0.8006	0.10000E 01	0.20000E 01
14	1.1086	0.10000E 01	0.20000E 01
15	1.1086	0.10000E 01	0.20000E 01
16	0.8006	0.10000E 01	0.00000E 00
17	1.1086	0.10000E 01	0.00000E 00
18	1.1086	0.10000E 01	0.00000E 00

RESULTS FROM ANALYSIS OF CURRENT EXPERIMENT

ANALYSIS OF VARIANCE BASED ON NATURAL LOG OF OBSERVATIONS

SUM SQUARES	MEAN SQUARE	DEGREES OF FREEDOM
0.21752E 01	0.13595E 00	0.16000E 02

TERM	ESTIMATES	INVERSE OF PRODUCT MATRIX (X'X)**-1	
1	0.79497E 01	0.19722E 00	
2	-0.23670E-01	-0.38892E-01	0.10677E-01

CONDITION(MIN EIGNVAL/MAX EIGNVAL) OF TRIANGULAR MATRIX: COND=0.4384E 00
DETERMINANT OF NORMALIZED INFORMATION MATRIX-PRODUCT X'X: DET=0.2817E 00

ANALYSIS OF RESIDUALS FOR CURRENT DATA ONLY

ITEM	WEIGHTING	OBSERVATION	PREDICTION	RESIDUAL	ITEM
1	1.1086	0.19500E 04	0.24593E 04	-0.50932E 03	1
2	1.1086	0.13500E 04	0.24593E 04	-0.11093E 04	2
3	1.3098	0.35000E 04	0.24593E 04	0.10407E 04	3
4	0.8006	0.33500E 04	0.24593E 04	0.89068E 03	4
5	1.1086	0.28500E 04	0.24593E 04	0.39068E 03	5
6	0.8006	0.31500E 04	0.24593E 04	0.69068E 03	6
7	1.1086	0.15000E 04	0.25182E 04	-0.10182E 04	7
8	1.1086	0.16500E 04	0.25182E 04	-0.86823E 03	8
9	0.8006	0.33000E 04	0.25182E 04	0.78177E 03	9
10	0.8006	0.33000E 04	0.25785E 04	0.72145E 03	10
11	0.9546	0.36500E 04	0.27035E 04	0.94645E 03	11
12	0.9546	0.35000E 04	0.27035E 04	0.79645E 03	12
13	0.8006	0.46000E 04	0.27035E 04	0.18964E 04	13
14	1.1086	0.29500E 04	0.27035E 04	0.24645E 03	14
15	1.1086	0.31500E 04	0.27035E 04	0.44645E 03	15
16	0.8006	0.34000E 04	0.28346E 04	0.56538E 03	16
17	1.1086	0.18000E 04	0.28346E 04	-0.10346E 04	17
18	1.1086	0.20000E 04	0.28346E 04	-0.83462E 03	18

TABLE 5.10-7

LEAST SQUARE SOLUTION OF LINEAR EQUATIONS Y=X*B+ERROR
7. RABBIT REDESIGNED PASSIVE BELT --- WEAKEST COMPONENT FAILS SEATBELT SYSTEM

ITEM	WEIGHTING	ALLOCATION MATRIX OF COEFFICIENTS X(I,J)	
1	0.8824	0.10000E 01	0.60000E 01
2	1.5880	0.10000E 01	0.60000E 01
3	1.5880	0.10000E 01	0.60000E 01
4	0.8824	0.10000E 01	0.60000E 01
5	0.8824	0.10000E 01	0.60000E 01
6	0.8824	0.10000E 01	0.60000E 01
7	0.8824	0.10000E 01	0.50000E 01
8	0.8824	0.10000E 01	0.50000E 01
9	0.8824	0.10000E 01	0.50000E 01
10	0.8824	0.10000E 01	0.40000E 01
11	0.8824	0.10000E 01	0.20000E 01
12	0.8824	0.10000E 01	0.20000E 01
13	0.8824	0.10000E 01	0.20000E 01
14	0.8824	0.10000E 01	0.20000E 01
15	0.8824	0.10000E 01	0.20000E 01
16	0.8824	0.10000E 01	0.00000E 00
17	1.5880	0.10000E 01	0.00000E 00
18	0.8824	0.10000E 01	0.00000E 00

RESULTS FROM ANALYSIS OF CURRENT EXPERIMENT

ANALYSIS OF VARIANCE BASED ON NATURAL LOG OF OBSERVATIONS

SUM SQUARES	MEAN SQUARE	DEGREES OF FREEDOM
0.26682E 00	0.16677E-01	0.16000E 02

TERM	ESTIMATES	INVERSE OF PRODUCT MATRIX (X'X)**-1	
1	0.81243E 01	0.19112E 00	
2	0.17262E-02	-0.37072E-01	0.10138E-01

CONDITION(MIN EIGNVAL/MAX EIGNVAL) OF TRIANGULAR MATRIX: COND=0.4272E 00
DETERMINANT OF NORMALIZED INFORMATION MATRIX-PRODUCT X'X: DET=0.2907E 00

ANALYSIS OF RESIDUALS FOR CURRENT DATA ONLY

ITEM	WEIGHTING	OBSERVATION	PREDICTION	RESIDUAL	ITEM
1	0.8824	0.35000E 04	0.34105E 04	0.89515E 02	1
2	1.5880	0.29410E 04	0.34105E 04	-0.46948E 03	2
3	1.5880	0.35000E 04	0.34105E 04	0.89515E 02	3
4	0.8824	0.33500E 04	0.34105E 04	-0.60484E 02	4
5	0.8824	0.33500E 04	0.34105E 04	-0.60484E 02	5
6	0.8824	0.31500E 04	0.34105E 04	-0.26048E 03	6
7	0.8824	0.37500E 04	0.34046E 04	0.34540E 03	7
8	0.8824	0.38000E 04	0.34046E 04	0.39540E 03	8
9	0.8824	0.33000E 04	0.34046E 04	-0.10460E 03	9
10	0.8824	0.33000E 04	0.33987E 04	-0.98732E 02	10
11	0.8824	0.36500E 04	0.33870E 04	0.26298E 03	11
12	0.8824	0.35000E 04	0.33870E 04	0.11298E 03	12
13	0.8824	0.46000E 04	0.33870E 04	0.12130E 04	13
14	0.8824	0.37000E 04	0.33870E 04	0.31298E 03	14
15	0.8824	0.35500E 04	0.33870E 04	0.16298E 03	15
16	0.8824	0.34000E 04	0.33753E 04	0.24654E 02	16
17	1.5880	0.26180E 04	0.33753E 04	-0.75734E 03	17
18	0.8824	0.36000E 04	0.33753E 04	0.22465E 03	18

TABLE 5.10-8

LEAST SQUARE SOLUTION OF LINEAR EQUATIONS Y=X*B+ERROR
8. CHEVETTE MANUAL/PASSIVE BELTS --- WEAKEST COMPONENT FAILS SEATBELT SYSTEM

ITEM	WEIGHTING	ALLOCATION MATRIX OF COEFFICIENTS X(I,J)	
1	0.8403	0.10000E 01	0.50000E 01
2	1.3445	0.10000E 01	0.50000E 01
3	0.9604	0.10000E 01	0.50000E 01
4	1.0924	0.10000E 01	0.50000E 01
5	0.9604	0.10000E 01	0.50000E 01
6	0.9604	0.10000E 01	0.50000E 01
7	0.9604	0.10000E 01	0.00000E 00
8	0.9604	0.10000E 01	0.00000E 00
9	0.9604	0.10000E 01	0.00000E 00
10	0.9604	0.10000E 01	0.00000E 00

RESULTS FROM ANALYSIS OF CURRENT EXPERIMENT

ANALYSIS OF VARIANCE BASED ON NATURAL LOG OF OBSERVATIONS

SUM SQUARES	MEAN SQUARE	DEGREES OF FREEDOM
0.66833E 00	0.83541E-01	0.80000E 01

TERM	ESTIMATES	INVERSE OF PRODUCT MATRIX (X'X)**-1	
1	0.79386E 01	0.26031E 00	
2	-0.11771E-01	-0.52061E-01	0.16907E-01

CONDITION(MIN EIGNVAL/MAX EIGNVAL) OF TRIANGULAR MATRIX: COND=0.4112E 00
DETERMINANT OF NORMALIZED INFORMATION MATRIX-PRODUCT X'X: DET=0.3842E 00

ANALYSIS OF RESIDUALS FOR CURRENT DATA ONLY

ITEM	WEIGHTING	OBSERVATION	PREDICTION	RESIDUAL	ITEM
1	0.8403	0.29000E 04	0.26431E 04	0.25688E 03	1
2	1.3445	0.35500E 04	0.26431E 04	0.90688E 03	2
3	0.9604	0.22350E 04	0.26431E 04	-0.40812E 03	3
4	1.0924	0.33000E 04	0.26431E 04	0.65688E 03	4
5	0.9604	0.21470E 04	0.26431E 04	-0.49612E 03	5
6	0.9604	0.18240E 04	0.26431E 04	-0.81912E 03	6
7	0.9604	0.21470E 04	0.28034E 04	-0.65636E 03	7
8	0.9604	0.21470E 04	0.28034E 04	-0.65636E 03	8
9	0.9604	0.40000E 04	0.28034E 04	0.11966E 04	9
10	0.9604	0.33500E 04	0.28034E 04	0.54665E 03	10

TABLE 5.10-9

LEAST SQUARE SOLUTION OF LINEAR EQUATIONS Y=X*B+ERROR
9. CHEVETTE REDESIGNED PASSIVE BELT --- WEAKEST COMPONENT FAILS SEATBELT SYSTEM

ITEM	WEIGHTING	ALLOCATION MATRIX OF COEFFICIENTS X(I,J)	
1	0.5731	0.10000E 01	0.50000E 01
2	1.1461	0.10000E 01	0.50000E 01
3	0.5731	0.10000E 01	0.50000E 01
4	0.8596	0.10000E 01	0.50000E 01
5	1.4327	0.10000E 01	0.50000E 01
6	1.4327	0.10000E 01	0.50000E 01
7	1.1461	0.10000E 01	0.00000E 00
8	0.5731	0.10000E 01	0.00000E 00
9	0.1248	0.10000E 01	0.00000E 00
10	0.5792	0.10000E 01	0.00000E 00

RESULTS FROM ANALYSIS OF CURRENT EXPERIMENT

ANALYSIS OF VARIANCE BASED ON NATURAL LOG OF OBSERVATIONS

SUM SQUARES	MEAN SQUARE	OEGREES OF FREEOOM
0.51360E 00	0.79745E-01	0.64405E 01

TERM	ESTIMATES	INVERSE OF PROOUCT MATRIX (X'X)**-1	
1	0.82256E 01	0.41268E 00	
2	-0.70477E-01	-0.82536E-01	0.23155E-01

CONDITION(MIN EIGNVAL/MAX EIGNVAL) OF TRIANGULAR MATRIX: COND=0.4421E 00
DETERMINANT OF NORMALIZEO INFORMATION MATRIX-PROOUCT X'X: DET=0.2871E 00

ANALYSIS OF RESIOUALS FOR CURRENT OATA ONLY

ITEM	WEIGHTING	OBSERVATION	PREOICTION	RESIDUAL	ITEM
1	0.5731	0.29000E 04	0.26260E 04	0.27397E 03	1
2	1.1461	0.35500E 04	0.26260E 04	0.92397E 03	2
3	0.5731	0.38000E 04	0.26260E 04	0.11740E 04	3
4	0.8596	0.33000E 04	0.26260E 04	0.67397E 03	4
5	1.4327	0.21470E 04	0.26260E 04	-0.47903E 03	5
6	1.4327	0.18240E 04	0.26260E 04	-0.80203E 03	6
7	1.1461	0.36000E 04	0.37354E 04	-0.13543E 03	7
8	0.5731	0.40000E 04	0.37354E 04	0.26457E 03	8
9	0.1248	0.24250E 04	0.37354E 04	-0.13104E 04	9
10	0.5792	0.41220E 04	0.37354E 04	0.38657E 03	10

EXIT PROGRAM
FOR INPUT INSTRUCTION IPRINT(1)= 0 FOR REPEAT RESULTS IPRINT(2)= 0
FOR OIAGNOSTIC OUTPUT NPRINT= 0 FOR THE MAIN ROUTINE
0 FOR SUBROUTINE OBSERV
0 FOR SUBROUTINE INVERT
0 FOR SUBROUTINE RESID
INS=-1 INX=-1 INY= 0 INW= 0 INR= 0 M= 0 N= 0

FIN SINCE INS=INX=-1 OR INS=IPRINT(2)=0 + INX=-1

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ROUTINE CENSOR ESTIMATES MEAN, STANDARD DEVIATION AND DEGREES OF FREEDOM
FOR NORMALLY DISTRIBUTED DATA WHICH IS CENSORED AT SEVERAL LEVELS
(MULTI-LEVEL TYPE 1 CENSORING)

$$$  4. TOYOTA PASSIVE SHOULDER BELT OF PASSIVE SYSTEM          X
NUMBER OF UNCENSORED SAMPLE VALUES    N=  23
NUMBER OF CENSOR LEVELS           LEVELS=   1
MAX NUMBER OF ITERATIONS ALLOWED  LMTRY=  30
ERROR TO SIGNAL CONVERGENCE       ERLIM=0.100D-07

UNCENSORED SAMPLE VALUES:
    0.35000000D+04    0.41500000D+04    0.36000000D+04    0.25500000D+04    0.31500000D+04    0.44500000D+04    0.33500000D+04
    0.31500000D+04    0.40000000D+04    0.38000000D+04    0.33500000D+04    0.36000000D+04    0.40500000D+04    0.42500000D+04
    0.35500000D+04    0.34500000D+04    0.37000000D+04    0.33000000D+04    0.37000000D+04    0.31000000D+04    0.29000000D+04
    0.39500000D+04    0.36000000D+04

CENSORED DATA

GROUP     CENSOR LEVEL     NUMBER OF HIDDEN VALUES
  1     0.3400000D+04         1

$$$  4. TOYOTA PASSIVE SHOULDER BELT OF PASSIVE SYSTEM          X=DLOG(X)
CONVERTED DATA FOR WHICH TERMS TO BE COMPUTED:

UNCENSORED VALUES:
   -0.81605182D+01   -0.83308636D+01   -0.81886891D+01   -0.78438486D+01   -0.80551577D+01   -0.84006594D+01   -0.81167156D+01
   -0.80551577D+01   -0.82940496D+01   -0.82427563D+01   -0.81167156D+01   -0.81886891D+01   -0.83064722D+01   -0.83546743D+01
   -0.81747029D+01   -0.81461295D+01   -0.82160881D+01   -0.81016777D+01   -0.82160881D+01   -0.80391574D+01   -0.79724660D+01
   -0.82814709D+01   -0.81886891D+01

CENSORED DATA

GROUP     CENSOR LEVEL     NUMBER OF HIDDEN VALUES
  1    -0.8131531D+01         1

FOR UNCENSORED DATA, N= 23  AVERAGE=-.817354D+01  EMS=0.160802D-01
INITIAL: MEAN=-.817179D+01  STD DEV=0.127110D+00  FOR   1 CENSORED VALUES AT  1 LEVELS IN  24 TOTAL SAMPLES
TRY  1:  MEAN=-.817434D+01  STD DEV=0.128103D+00  ERROR=0.255D-02  EFFECTIVE NUMBER=   0.546 IN   1 CENSORED
TRY  2:  MEAN=-.817561D+01  STD DEV=0.128589D+00  ERROR=0.126D-02  EFFECTIVE NUMBER=   0.539 IN   1 CENSORED
TRY  3:  MEAN=-.817623D+01  STD DEV=0.128828D+00  ERROR=0.625D-03  EFFECTIVE NUMBER=   0.536 IN   1 CENSORED
TRY  4:  MEAN=-.817654D+01  STD DEV=0.128944D+00  ERROR=0.309D-03  EFFECTIVE NUMBER=   0.534 IN   1 CENSORED
TRY  5:  MEAN=-.817669D+01  STD DEV=0.129002D+00  ERROR=0.153D-03  EFFECTIVE NUMBER=   0.533 IN   1 CENSORED
TRY  6:  MEAN=-.817677D+01  STD DEV=0.129030D+00  ERROR=0.755D-04  EFFECTIVE NUMBER=   0.533 IN   1 CENSORED
TRY  7:  MEAN=-.817681D+01  STD DEV=0.129043D+00  ERROR=0.373D-04  EFFECTIVE NUMBER=   0.533 IN   1 CENSORED
TRY  8:  MEAN=-.817683D+01  STD DEV=0.129050D+00  ERROR=0.184D-04  EFFECTIVE NUMBER=   0.532 IN   1 CENSORED
TRY  9:  MEAN=-.817683D+01  STD DEV=0.129053D+00  ERROR=0.911D-05  EFFECTIVE NUMBER=   0.532 IN   1 CENSORED
TRY 10:  MEAN=-.817684D+01  STD DEV=0.129055D+00  ERROR=0.450D-05  EFFECTIVE NUMBER=   0.532 IN   1 CENSORED
TRY 11:  MEAN=-.817684D+01  STD DEV=0.129056D+00  ERROR=0.222D-05  EFFECTIVE NUMBER=   0.532 IN   1 CENSORED
TRY 12:  MEAN=-.817684D+01  STD DEV=0.129056D+00  ERROR=0.110D-05  EFFECTIVE NUMBER=   0.532 IN   1 CENSORED
TRY 13:  MEAN=-.817684D+01  STD DEV=0.129056D+00  ERROR=0.543D-06  EFFECTIVE NUMBER=   0.532 IN   1 CENSORED
TRY 14:  MEAN=-.817684D+01  STD DEV=0.129057D+00  ERROR=0.268D-06  EFFECTIVE NUMBER=   0.532 IN   1 CENSORED
TRY 15:  MEAN=-.817684D+01  STD DEV=0.129057D+00  ERROR=0.132D-06  EFFECTIVE NUMBER=   0.532 IN   1 CENSORED
TRY 16:  MEAN=-.817684D+01  STD DEV=0.129057D+00  ERROR=0.654D-07  EFFECTIVE NUMBER=   0.532 IN   1 CENSORED
TRY 17:  MEAN=-.817684D+01  STD DEV=0.129057D+00  ERROR=0.323D-07  EFFECTIVE NUMBER=   0.532 IN   1 CENSORED
TRY 18:  MEAN=-.817684D+01  STD DEV=0.129057D+00  ERROR=0.159D-07  EFFECTIVE NUMBER=   0.532 IN   1 CENSORED
TRY 19:  MEAN=-.817684D+01  STD DEV=0.129057D+00  ERROR=0.787D-08  EFFECTIVE NUMBER=   0.532 IN   1 CENSORED
OUT OF  24 TOTAL SAMPLED WITH AN EFFECTIVE TOTAL=  23.532 FOR  22.532 DEGREES OF FREEDOM
THE GEOMETRIC MEAN=0.355761D+04
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TABLE 5.12

Loads on Frontal Impact
at 29.4 Miles per Hour

C. S. Davis
NHTSA Seatbelts
2-15-82

	x_i Peak Loads in (lbs)	$\bar{x} = e^{\frac{1}{n}\Sigma_i \ln x_i}$ Geometric Average in (lbs)	s^2 Variance on logarithms of loadings	s estimated Standard deviation in (lbs)	
1976 VW Rabbit manual seatbelt $n = 4$ $df = 3$	1140 1280 1678 1025	1258.658	.044982	.21209	
1978 Chevette manual seatbelt $n = 2$ $df = 1$	1597 1534	1565.183	.00081000	.02846	
1980 Toyota Corona automatic seatbelt (torso) $n = 2$ $df = 1$	1884 2141	2008.393	.0081762	.09042	

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TABLE 5.13

Computation of Load-Strength Standard Deviation

C.S. Davis
NHTSA seatbelts
2-16-82

MEAN SQUARE σ^2	model gradients: term i	$\frac{df}{d\beta_i}$	variance-covariance matrix: term ij	element σ_{ij}^2	product term: terms $i \times j$	σ_{ij}^2	projected variance on predicted strength σ_1^2	variance on loads @ 27.4 mph σ_2^2	load-strength standard dev $[\sigma_1^2+\sigma_2^2]^{1/2}$
1. Toyota manual belt --- both belts or buckle system fails for system failure									
.069029	1	1	σ_{11}^2	$.18199\sigma^2$	1×1	σ_{11}^2	$.18199\sigma^2$	.012563	.008176	.14401
	2_{NEW}	0	σ_{12}^2	$-.027533\sigma^2$	1×2	σ_{12}^2	$-.13767\sigma^2$	predicted for NEW belts in 1981		
	2_{1976}	5	σ_{21}^2	$-.027533\sigma^2$	2×1	σ_{21}^2	$-.13767\sigma^2$	predicted for 1976 belts in 1981		
			σ_{22}^2	$.0060191\sigma^2$	2×2	σ_{22}^2	$.15048\sigma^2$	.003944	.008176	.11009
2. Toyota manual belt — weakest belt fails and other still functions									
.027818	1	1	σ_{11}^2	$.20714\sigma^2$	1×1	σ_{11}^2	$.20714\sigma^2$	.005762	.008176	.11806
	2_{NEW}	0	σ_{12}^2	$-.031917\sigma^2$	1×2	σ_{12}^2	$-.15958\sigma^2$	predicted for NEW belts in 1981		
	2_{1976}	5	σ_{21}^2	$-.031917\sigma^2$	2×1	σ_{21}^2	$-.15959\sigma^2$	predicted for 1976 belts in 1981		
			σ_{22}^2	$.0062685\sigma^2$	2×2	σ_{12}^2	$.17171\sigma^2$	.001660	.008176	.09918
3. Toyota redesigned passive belt --- manual lap belt of system									
.086827	1	1	σ_{11}^2	$.15513\sigma^2$	1×1	σ_{11}^2	$.15513\sigma^2$	.013469	.008176	.14712
	2_{NEW}	0	σ_{12}^2	$-.023810\sigma^2$	1×2	σ_{12}^2	$-.11905\sigma^2$	predicted for NEW belts in 1981		
	2_{1976}	5	σ_{21}^2	$-.023810\sigma^2$	2×1	σ_{21}^2	$-.11905\sigma^2$	predicted for 1976 belts in 1981		
			σ_{22}^2	$.0049756\sigma^2$	2×2	σ_{12}^2	$.12978\sigma^2$	.004072	.008176	.11067
4. Toyota redesigned passive belt --- automatic shoulder belt of system									
.016346	1	1	σ_{11}^2	$.20367\sigma^2$	1×1	σ_{11}^2	$.20367\sigma^2$	.003330	.008176	.10726
	2_{NEW}	0	σ_{12}^2	$-.031558\sigma^2$	1×2	σ_{12}^2	$-.15778\sigma^2$	predicted for NEW belts in 1981		
	2_{1976}	5	σ_{21}^2	$-.031558\sigma^2$	2×1	σ_{21}^2	$-.15778\sigma^2$	predicted for 1976 belts in 1981		
			σ_{22}^2	$.0067473\sigma^2$	2×2	σ_{12}^2	$.17366\sigma^2$	.001010	.008176	.09584
All data pooled together ⟹ No regression ⟹								.016656	.008176	.15758
5. Rabbit manual belt --- weakest component fails seatbelt system									
.12467	1	1	σ_{11}^2	$.21650\sigma^2$	1×1	σ_{11}^2	$.21650\sigma^2$	.026991	.044982	.26828
	2_{NEW}	0	σ_{12}^2	$-.041531\sigma^2$	1×2	σ_{12}^2	$-.20765\sigma^2$	predicted for NEW belts in 1981		
	2_{1976}	5	σ_{21}^2	$-.041531\sigma^2$	2×1	σ_{21}^2	$-.20766\sigma^2$	predicted for 1976 belts in 1981		
			σ_{22}^2	$.010717\sigma^2$	2×2	σ_{12}^2	$.267925\sigma^2$	.008617	.044982	.23151
6. Rabbit passive belt --- weakest component fails seatbelt system									
.13595	1	1	σ_{11}^2	$.19722\sigma^2$	1×1	σ_{11}^2	$.19722\sigma^2$	.026812	.044982	.26794
	2_{NEW}	0	σ_{12}^2	$-.038892\sigma^2$	1×2	σ_{12}^2	$-.19446\sigma^2$	predicted for NEW belts in 1981		
	2_{1976}	5	σ_{21}^2	$-.038892\sigma^2$	2×1	σ_{21}^2	$-.19446\sigma^2$	predicted for 1976 belts in 1981		
			σ_{22}^2	$.010677\sigma^2$	2×2	σ_{12}^2	$.266725\sigma^2$	.010227	.044982	.23497
7. Rabbit redesigned passive belt — weakest component fails seatbelt system									
.016677	1	1	σ_{11}^2	$.19112\sigma^2$	1×1	σ_{11}^2	$.19112\sigma^2$	.003187	.044982	.21948
	2_{NEW}	0	σ_{12}^2	$-.037072\sigma^2$	1×2	σ_{12}^2	$-.18536\sigma^2$	predicted for NEW belts in 1981		
	2_{1976}	5	σ_{21}^2	$-.037072\sigma^2$	2×1	σ_{21}^2	$-.18536\sigma^2$	predicted for 1976 belts in 1981		
			σ_{22}^2	$.010138\sigma^2$	2×2	σ_{12}^2	$.25345\sigma^2$	.001232	.044982	.21497
All data pooled together ⟹ No regression ⟹								.013303	.044982	.24142
8. Chevette manual/passive belts — weakest component fails seatbelt system									
.083541	1	1	σ_{11}^2	$.26031\sigma^2$	1×1	σ_{11}^2	$.26031\sigma^2$	.021747	.000810	.15019
	2_{NEW}	0	σ_{12}^2	$-.052061\sigma^2$	1×2	σ_{12}^2	$-.26030\sigma^2$	predicted for NEW belts in 1981		
	2_{1976}	5	σ_{21}^2	$-.052061\sigma^2$	2×1	σ_{21}^2	$-.26031\sigma^2$	predicted for 1976 belts in 1981		
			σ_{22}^2	$.016907\sigma^2$	2×2	σ_{22}^2	$.422675\sigma^2$	.013565	.000810	.11990
9. Chevette redesigned passive belt --- weakest component fails seatbelt system									
.079745	1	1	σ_{11}^2	$.41268\sigma^2$	1×1	σ_{11}^2	$.41268\sigma^2$	.032909	.000810	.18363
	2_{NEW}	0	σ_{12}^2	$-.082536\sigma^2$	1×2	σ_{12}^2	$-.41268\sigma^2$	predicted for NEW belts in 1981		
	2_{1976}	5	σ_{21}^2	$-.082536\sigma^2$	2×1	σ_{21}^2	$-.41268\sigma^2$	predicted for 1976 belts in 1981		
			σ_{22}^2	$.023155\sigma^2$	2×2	σ_{22}^2	$.578875\sigma^2$	.013253	.000810	.11859

Notes
1. For Toyota manual belts — all calculations are for driver's seatbelt only as weakest
2. All computations are for logarithms of loads or strength with data assumed log normal

TABLE 5.14

Computation of Load-Strength Failure Probability

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NHTSA Seatbelts

i Seatbelt unit or subsystem	initial service date j	σ load-strength log standard deviation	$\bar{x}_1$ geometric mean strength in (lbs)	$\bar{x}_2$ geometric mean load at 29.4 mph	$\bar{z}$ statistic log normal $z = \ln \frac{\bar{x}_1}{\bar{x}_2} / \sigma$	estimated probability of failure P_{sij}
1. Toyota Corona manual belt both belts or buckle system fails for system failure	NEW	.14401	2908.8	2008.4	2.572	.005056
	1976	.11009	2560.1	2008.4	2.205	.013727
2. Toyota Corona manual belt weakest belt fails and other still functions	NEW	.11806	2622.2	2008.4	2.259	.011942
	1976	.09918	2042.9	2008.4	.172	.431719
3. Toyota Corona redesigned passive belt manual lap belt of system	NEW	.14712	2930.2	2008.4	2.568	.005114
	1976	.11067	2679.2	2008.4	2.604	.004607
4. Toyota Corona redesigned passive belt automatic shoulder belt of system	NEW	.10726	3377.9	2008.4	4.847	.000000 63
	1976	.09584	3487.5	2008.4	5.758	.000000 005
	combined	.15758	3557.6	2008.4	3.628	.000143
5. Rabbit manual belt weakest component fails seatbelt system	NEW	.26828	2806.2	1258.7	2.988	.001404
	1976	.23151	2582.2	1258.7	3.104	.000955
6. Rabbit passive belt Weakest component fails seatbelt system	NEW	.26794	2834.6	1258.7	3.030	.001223
	1976	.23497	2518.2	1258.7	2.951	.001584
7. Rabbit redesigned passive belt Weakest component fails seatbelt system	NEW	.21948	3375.3	1258.7	4.494	.000003 50
	1976	.21497	3404.6	1258.7	4.629	.000001 84
	combined	.24142	3453.7	1258.7	4.181	.000014 5
8. Chevette manual /passive belts Weakest component fails seatbelt system	NEW	.15019	2803.4	1565.2	3.881	.000052 0
	1976	.11990	2643.1	1565.2	4.370	.000006 21
9. Chevette redesigned manual/passive belts Weakest component fails seatbelt system	NEW	.18363	3735.4	1565.2	4.737	.000001 09
	1976	.11859	2626.0	1565.2	4.363	.000006 42

Note: passive = automatic seatbelt design

TABLE 5.15

Assembly of Seatbelt Reliability for Selected Cases

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NHTSA Seatbelts

Seatbelt System /Reliability equation	age class of seatbelts: initial service date	age in years j	Probabilities of failure: load-strength: first subsystem P_{s1j}	load-strength: second subsystem (if any) $P_{s1\&2j}$	retractor displacement P_d	SEATBELT RELIABILITY in a 29.4mph frontal impact R
1. Corona manual seatbelt pre-79 $R = (1-P_{s1j})(1-P_d^2)(1-P_{s2j}P_d)$	NEW	0	.005056	.011942	.005355	.9949
	1976	5	.013727	.431719	.005355	.9840
2. Corona passive (shoulder belt only) $R = (1-P_{s4j})(1-P_d)$ Note: motor and attachment to motor assumed not to reduce reliability	NEW	0	.000000 63	—	.005355	.9946
	1976	5	.000000 605	—	.005355	.9946
	combined	A	.000143	—	.005355	.9945
3. Corona passive (with lapbelt secure) $R = (1-P_{s3j}P_{s4j})(1-P_d^2)(1-P_{s3j}P_d)(1-P_{s4j}P_d)$ Note: motor and attachment to motor assumed not to reduce reliability	NEW by combined	0=A	.005114	.000143	.005355	.9999 42
	1976 by combined	5=A	.004607	.000143	.005355	.9999 45
4. Rabbit manual seatbelt $R = (1-P_{s5j})(1-P_d)$	NEW	0	.001404	—	.009064	.9895
	1976	5	.000955	—	.009064	.9900
5. Rabbit passive seatbelt $R = (1-P_{s6j})(1-P_d)$	NEW	0	.001223	—	.009064	.9897
	1976	5	.001584	—	.009064	.9894
6. Rabbit redesigned passive seatbelt $R = (1-P_{s7j})(1-P_d)$	NEW	0	.000003 50	—	.009064	.9909
	1976	5	.000001 84	—	.009064	.9909
	combined	A	.000014 5	—	.009064	.9909
7. Chevette manual/passive seatbelts $R = (1-P_{s8j})(1-P_d)$ Note: For passive systems, shoulder web and attachments assumed not to reduce or add to reliability	NEW	0	.000052 0	—	.002769	.9972
	1976	5	.000006 21	—	.002769	.9972
8. Chevette redesigned m/p seatbelts $R = (1-P_{s9j})(1-P_d)$ Note: For passive systems, shoulder web and attachments assumed NOT to reduce or increase reliability	NEW	0	.000001 09	—	.002769	.9972
	1976	5	.000006 42	—	.002769	.9972

Notes: 1. "A" indicates average of all data with age and usage not modeled
2. passive = automatic seatbelt design

TABLE 5.16-1

Proportions Among Results From Hardware Identification Program
Los Angeles Metropolitan Area

Description of Outcome	Toyota Corona	VW Rabbit	Chevette	All Vehicles
Total Number Identified (R.L. Polk)	1498	702	213	2413
Nonresponse (no telephone listed, sold or no contact)	1229	583	183	1995
• as % of total identified	82%	83%	86%	83%
Response	269	119	30	418
Seatbelts not used often	50	9	7	66
• as % of respondants	19%	8%	23%	16%
Seatbelts used often (Users)	219	110	23	352
Users with no problems	144	71	16	231
• as % of all users	66%	65%	70%	66%
Users with problems	75	39	7	121
• as % of all users (Complaint rate) →	34%	35%	30%	34%
Users with Reliability problems	11	6	1	18
• as % of all users (Failure rate) →	5%	5%	4%	5%
Readiness problems only	64	33	6	103
Reliability problems only	5	5	0	10
Both types of problems	6	1	1	8
→ Problems as % of total identified (pool for seatbelt selection)	5%	6%	3%	5%

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TABLE 5.16-2

Proportions Among Results From Hardware Identification Program
Phoenix Metropolitan Area

Description of Outcome	Toyota Corona	VW Rabbit	Chevette	All Vehicles
Total Number Identified (R.L. Polk)	397	223	86	706
Nonresponse (no telephone listed, sold or no contact)	293	156	58	507
• as % of total identified	74%	70%	67%	72%
Response	104	67	28	199
Seatbelts not used often	19	8	5	32
• as % of respondants	18%	12%	18%	16%
Seatbelts used often (Users)	85	59	23	167
Users with no problems	51	26	10	87
• as % of all users	60%	44%	43%	52%
Users with problems	34	33	13	80
• as % of all users (Complaint rate) →	40%	56%	57%	48%
Users with Reliability problems	4	6	6	16
• as % of all users (Failure rate) →	5%	10%	26%	10%
Readiness problems only	30	27	7	64
Reliability problems only	2	3	2	7
Both types of problems	2	3	4	9
→ Problems as % of total identified (pool for seatbelt selection)	9%	15%	15%	11%

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TABLE 5.16-3

Proportions Among Results From Hardware Identification Program
Denver Metropolitan Area

Description of Outcome	Toyota Corona	VW Rabbit	Chevette	All Vehicles
Total Number Identified (R.L.Polk)	386	338	165	889
Nonresponse (no telephone listed, sold or no contact) • as % of total identified	211 55%	237 70%	97 59%	545 61%
Response	175	101	63	344
Seatbelts not used often • as % of respondants	28 16%	11 11%	13 19%	52 15%
Seatbelts used often (Users)	147	90	55	292
Users with no problems • as % of all users	92 63%	51 57%	25 45%	168 58%
Users with problems • as % of all users (Complaint rate) →	55 37%	39 43%	30 55%	124 42%
Users with Reliability problems • as % of all users (failure rate) →	11 7%	5 6%	3 5%	19 7%
Readiness problems only Reliability problems only Both types of problems	44 8 3	34 4 1	27 0 3	105 12 7
→ Problems as % of total identified (pool for seatbelt selection)	14%	12%	18%	14%

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TABLE 5.16-4

Proportions Among Results From Hardware Identification Program
Houston Metropolitan Area

Description of Outcome	Toyota Corona	VW Rabbit	Chevette	All Vehicles
Total Number Identified (R.L.Polk)	1047	428	322	1797
Nonresponse (no telephone listed, sold or no contact) ● as % of total identified	662 63%	269 63%	234 73%	1165 65%
Response	385	159	88	632
Seatbelts not used often ● as % of respondants	101 26%	29 18%	21 24%	151 24%
Seatbelts used often (Users)	284	130	67	481
Users with no problems ● as % of all users	225 79%	97 75%	50 75%	372 77%
Users with problems ● as % of all users (Complaint rate) →	59 21%	33 25%	17 25%	109 23%
Users with Reliability problems ● as % of all users (failure rate) →	9 3%	3 2%	4 6%	16 3%
Readiness problems only Reliability problems only Both types of problems	50 7 2	30 1 2	13 4 0	93 12 4
→ Problems as % of total identified (pool for seatbelt selection)	6%	8%	5%	6%

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TABLE 5.17

Summary
Proportions Among Results From Hardware Identification Program

Description of Outcome	Toyota Corona	VW Rabbit	Chevette	All Vehicles
Total Number Identified (R.L.Polk)	3328	1691	786	5805
Nonresponse (no telephone listed, sold or no contact)	2395	1245	572	4212
• as % of total identified	72%	74%	73%	73%
	55/82*	63/83	59/86	61/83
Response	933	446	214	1593
Seatbelts not used often	198	57	46	301
• as % of respondants	21%	13%	21%	19%
	16/26	8/18	18/24	15/24
Seatbelts used often (Users)	735	389	168	1292
Users with no problems	512	245	101	858
• as % of all users	70%	63%	60%	66%
	79/60	75/44	75/43	77/52
Users with problems	223	144	67	434
• as % of all users (Complaint rate) →	30%	37%	40%	34%
	21/40	25/56	25/57	23/48
Users with Reliability problems	35	20	14	69
• as % of all users (Failure rate) →	5%	5%	8%	5%
	3/7	2/10	4/26	3/10
Readiness problems only	188	124	53	365
Reliability problems only	22	13	6	41
Both types of problems	13	7	8	28
→ Problems as % of total identified (pool for seatbelt selection)	7%	9%	9%	7%
	5/14	6/15	3/18	5/14

* Typically, 55/82 represents the lowest and highest percentages, respectively, taken from the four metropolitan areas studied.

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TABLE 5.18

Comparison of Manual and Automatic
VW Rabbit Seatbelts for
Proportions Among Results from Hardware Identification Program

manual seatbelts				automatic seatbelts		
75/76 model years	79 model year	All model years		75/76 model years	79 model year	All model years
187	92	279	responses	71	96	167
67% →	33% →	100%	as a percentage of all responses	43% →	57% →	100%
28	19	47	non users	5	5	10
15%	21%	17% 6/28*	as a percentage of responses	7%	5%	6% 0/9
159	73	232	seatbelt users	66	91	157
69% →	31% →	100%	as a percentage of all users	42% →	58% →	100%
73	29	102	Complaints	14	28	42
46%	40%	44% 22/63	as a percentage of users	21%	31%	27% 20/29
14	2	16	Failures	1	3	4
8.8%	2.7%	6.9% 3/12	as a percentage of users	1.5%	3.3%	2.5% 0/6

* Typically, 6/28 represents the lowest and highest percentages, respectively, taken from the four metropolitan areas studied.

6.0 RECOMMENDATIONS

As a result of the research reflected in this program, FAA recommends the following four studies to further understanding of automatic restraint reliability.

1. Available vehicle accident data bases should be studied to determine role of seat belts among other contributors to death and injury in motor vehicles as a function of accident environment and to define accident environments. This is currently done in part in National Accident Severity Studies, but it requires further detailed analysis, including:
   - Assess code systems for State motor vehicle accident data bases, NEISS, FARS, and other collision performance data bases of HSRI, HSRC, and NHTSA.
   - Analysis of the data bases to count injuries and fatalities of seat belt users and assess failure modes and accident environments
   - Analysis of the data bases to count total accident involvement of seat belt users for corresponding accident circumstances and define distribution of environments
   - Compute and rank injury and fatality rates for seat belt failure and other contributors, if this detail can be obtained
2. Engineering studies are needed to determine restraint system environment response to selected accidents and assess restraint component mechanics and design alternatives. This may require, amongst other things:

- The NHTSA to obtain drawings, specifications, stress reports, test data, field test data on seat belts and associated vehicle structure from manufacturers
- Conducting formal survey and field inspections on seat belt usage and condition to determine usage rates of seat belts, problem rates, failure rates, and user experience and to obtain sample used seat belts for testing
- Testing restraint systems with anthropomorphic dummies on test track sled systems to measure occupant and seat belt component loads and displacements in response to given accident and vehicle energy absorption conditions
- Obtaining available and additional data on vehicle energy absorption and restraint system loads and deceleration response
- Studying mechanics of retractor catch systems to assess engagement stability with acceleration rates and possible design improvements including inspectability for maintenance and replacement
- Evaluating restraint system, occupant, cab interior, and associated vehicle structure as a system to determine alternative changes that could affect occupant safety in respect to restraint reliability, and ease of inspection, maintenance and replacement
- Conducting additional laboratory strength tests as needed on seat belts and selected components

3. Economic studies are needed to determine consequent losses from seat belt failure, its importance relative to other causes of

vehicle accident loss, and the total cost of developing improved seat belts to reduce losses. This will probably require examination of:

- Hospital records, dealership records, court records, and other sources to assess dollar losses from lost work time, hospital, litigation, investigation, property loss, vehicle repair in vehicle accidents, injuries, and deaths with and without seat belt failure
- Manufacturer records, dealership records, and other sources to assess total costs of seat belt requirement upgrades. Costs should include lead time investment and interest costs and consequences of scarce talent redirection
- Other motor vehicle safety factors, including highway environment, traffic, vehicle design, state inspection requirements, auto mechanics training and licensing to obtain some ranking of factors by cost per death or injury forestalled

4. Finally a study to optimize regulatory action might produce tremendous cost savings in final regulation. This effort would require:

- Combining results of preceding tasks to compute current risk = cost times probability of loss
- Using results to compute effect of changes in seat belt performance requirements
- Computing benefit minus cost as a function of change in restraint system performance requirements and assess optimum change within limits of analysis validity - assess validity

- Comparing benefit minus cost payoff for restraint system recommended requirements with estimated payoff that might be possible with NHTSA action on other factors

REFERENCES

1. Crow, E.L., Davis, F.A., and M.W. Maxfield, Statistics Manual, NAVORD Report 3369, Dover Publishers, 1960.

2. Johnson, D.P., Toomay, T.L., and Davis, C.S., "Estimation of the Defect Detection Probability for Ultrasonic Tests on Thick Section Steel Weldments," EPRI Technical Report NP-991 (February 1979) (Appendix B).

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